Appendix A. Regression to the mean

This description of the statistical concept of regression to the mean was provided by Dr. William M. Trochim, a professor in the Department of Policy Analysis and Management at Cornell University, and is available on the web at:

http://trochim.human.cornell.edu/kb/regrmean.htm.

Appendix B. Detailed analysis of program data

B.1. Summary

The result of every Smog Check inspection is reported to a central database, the Vehicle Information Database, or VID, via a phone modem connection. The value of the VID data is the enormous number of vehicle emissions measurements; virtually every vehicle reporting for I/M testing (roughly 9 million per year) is included in the VID database. The sheer number of measurements allows the analysis of very specific components of the program, such as results by test station type, air basin, cut point phase, etc.

However, since the VID measurements are used to determine whether a vehicle owner must pay for repairs, and pass a subsequent retest, the VID data do not necessarily give an accurate depiction of in-use emissions. There is a big incentive for a test station technician to minimize the emissions measurement, by over-preparing the vehicle for the test, in order to decrease the likelihood that the vehicle will fail the test. Some technicians may even falsify test results to ensure that a suspected high emitting vehicle passes the test. On the other hand, some test technicians may make efforts to increase the likelihood that a vehicle will fail the test, in order to charge the owner for unnecessary vehicle repairs. In addition, the emissions measured under the ASM test are not representative of on-road emissions, because the ASM test is run under an artificial condition of sustained constant load, which is rarely encountered in on-road driving in urban areas. As discussed above, vehicles are allowed to pass the test as soon as their emissions dip below the cut points; emissions of these vehicles that are passed after the minimum test time may not be comparable to emissions of vehicles given the full ASM test. Another limitation of the VID data is that emissions from exempted vehicles, or eligible vehicles avoiding the program, are not measured. Finally, regularly-scheduled biennial tests measure only the initial emission reduction from the program; they do not account for the decline in the emissions reduction benefit as repaired components deteriorate. The change of ownership test requirement in California, however, does provide data on the emissions of some vehicles at various times since their last passing Smog Check test.

B.2. Data quality and validity

In this section we discuss three aspects regarding the quality and validity of the program data reported in the VID: correct vehicle identification, valid emissions measurements, and correct test identification.

B.2.1. Correct vehicle identification

We use the vehicle identification number (VIN) to match multiple test records of the same vehicle. We use the VIN, rather than the license plate, to identify unique vehicles because all vehicles previously registered in other states have their license plates coded as N, OS, or NP (about 5% of all tests). There are a small number of obviously faulty VINs (blank, all the same character, etc.), but much fewer than uncoded license plates. Transcription errors may result in different tests of the same vehicle being associated to a different VIN. However, VINs on most 1981 and newer vehicles can be checked internally to determine whether or not they are valid.

There are three possible reasons for an invalid VIN on a 1981 and newer vehicle: (1) not all manufacturers used the standardized VIN positions on their 1981 vehicles; (2) an obviously false VIN; (3) an entry or transcription error. More than 99% of 1981 and newer vehicles have valid VINs. The likelihood that an entered VIN is invalid depends on the age of the vehicle. The fraction of invalid VINs ranges from 4% for 1981 vehicles to 0.1% for 1995 vehicles. The likelihood that an entered VIN is invalid also depends on how the VIN was entered into the VID system. VINs are entered into the VID by one of three methods: (1) 20% of all VINs are scanned electronically from the bar code on the vehicle; (2) 57% are scanned electronically from the bar code on the registration notice mailed by DMV to the vehicle owner; and (3) 23% are read from the vehicle and manually entered into the system. Scanning the VIN electronically from the vehicle results in the lowest rate of invalid VINs; 0.1% of VINs entered this way are invalid. 0.6% of the VINs scanned from the DMV notice are invalid, while 1.7% of the manually entered VINs are invalid. VINs are manually entered for 33% of 1981 vehicles, compared with only 7% of 1995 vehicles. Since older vehicles are more likely to have their VIN entered manually than newer vehicles, some of the difference in the rate of invalid VINs by entry method may be due to the age of the vehicle.

Of those vehicles with valid VINs, over 98% have the correct model year and over 99% have the correct emissions standards category (model year and vehicle type, i.e. passenger car or truck). To check whether vehicles were properly passed or failed, we apply the appropriate Smog Check cut point to each vehicle and compare the measured emissions to the cutpoint. All of the vehicles with emissions higher than the applicable cut points were properly failed; however, a very small number (less than 1%) of the vehicles with emissions lower than the applicable cut point were improperly failed.

B.2.2. Valid emissions measurements

The VID allows the reporting of negative emissions values from ASM tests. A very small fraction of ASM 2525 tests result in negative emissions values: 0.04% for HC, 0.03% for NOx, and less than 0.01% for CO. There are quite a few zero measurements in the VID data; we assume these are legitimate emissions values. The fraction of zero ASM 2525 measurements is 3.5% for HC, 2.4% for NOx, and 15% for CO.

For all analyses we include only emissions measurements that met the following criteria:

- CO_2 greater than 0% but less than 18%;
- sum of CO_2 and CO less than 20%;
- NO less than 20,000 ppm; and
- O_2 less than 20%.

Only 0.14% of all VID records have a measurement of at least one pollutant that does not meet all of these critera. Most of the “invalid” measurements that we exclude from analysis have CO_2 emissions of 0%, or greater than 18%.

B.2.3. Correct test identification

The VID database does not explicitly identify the initial Smog Check test of each vehicle. The only way to ensure that the current test is the initial test of each vehicle is to examine previous months of data to identify any previous test of vehicles. We used one month of data, December 1998, to determine how many vehicles tested in a given month had an initial test in previous months. 7.1% of the vehicles tested in December 1998 had their initial test in a previous month; 2.4% had their initial test in November 1998, while the remaining 4.7% had their initial test in the previous 5 months. (We did not determine how many of these tests in previous months were tests from a previous Smog Check cycle.) Limiting analysis to one month of data will misidentify the initial test emissions of 7% of the fleet. Using several months of data will reduce the potential for misidentifying the initial test of some vehicles.

B.3. Data analysis

In this section we provide more detail on several aspects of the VID data. All emissions results reported are from the second mode of the ASM test, the 2525 test.[1] All average emissions measurements, and vehicle counts, reported are based on the number of vehicles given ASM tests at stations in Enhanced areas (we exclude from our analysis all-wheel drive vehicles and other vehicles that are otherwise not given an ASM test at Enhanced stations).[2]

B.3.1. No-final-pass rate

The program data indicate that 10% of all vehicles that failed their initial Smog Check test (or 1.3% of all vehicles) did not receive a passing test. This is based on an analysis of vehicles tested in the first two months of Phase 3 cut points only, allowing all vehicles nearly a year to obtain a final pass. However, some failing vehicles may take more than a year to obtain a passing test. Figure B-1 shows that the no-final-pass rate of vehicles tested under Phase 3 cut points steadily decreases as vehicles are given up to 10 months to pass. The figure indicates that 13% of all vehicles that fail their initial test do not receive a passing test within one month. However, only 10% of all failing vehicles do not receive a passing test within 11 months. Figure B-2 shows a similar result for 18 months of VID data. The no-final-pass rate is 14% of all vehicles that fail their initial test, if vehicles are given only one month to pass. The no-final-pass rate drops to 10% of all failing vehicles if they are given 10 or more months to pass. Because the no-final-pass rate never drops below 10% of all failing vehicles, we use this as our estimate of the "true" no-final-pass rate. (We do not have an explanation for why the no-final-pass rate

---

1. This test measures vehicle emissions at a slightly lower load on the vehicle than the first test, the 5015 test. However, we believe that the 5015 test may overstate vehicle emissions, particularly for clean vehicles that are tested for only 10 seconds on the 5015 test. Inconsistent preconditioning of vehicles prior to testing is perhaps the largest source of bias in emissions results for different vehicles in the VID.

2. Vehicles not given an ASM test are given the conventional two-speed idle test. All-wheel drive vehicles are not given an ASM test because they cannot be driven on the dynamometer. Technicians may determine that some other vehicles, for instance those with bald tires, cannot be safely driven on the dynamometer. Some vehicles tested in Enhanced areas are registered in non-Enhanced areas, and are not required to get an ASM test.

Figure B-1. No-Final-Pass rate by months of data, Phase 3

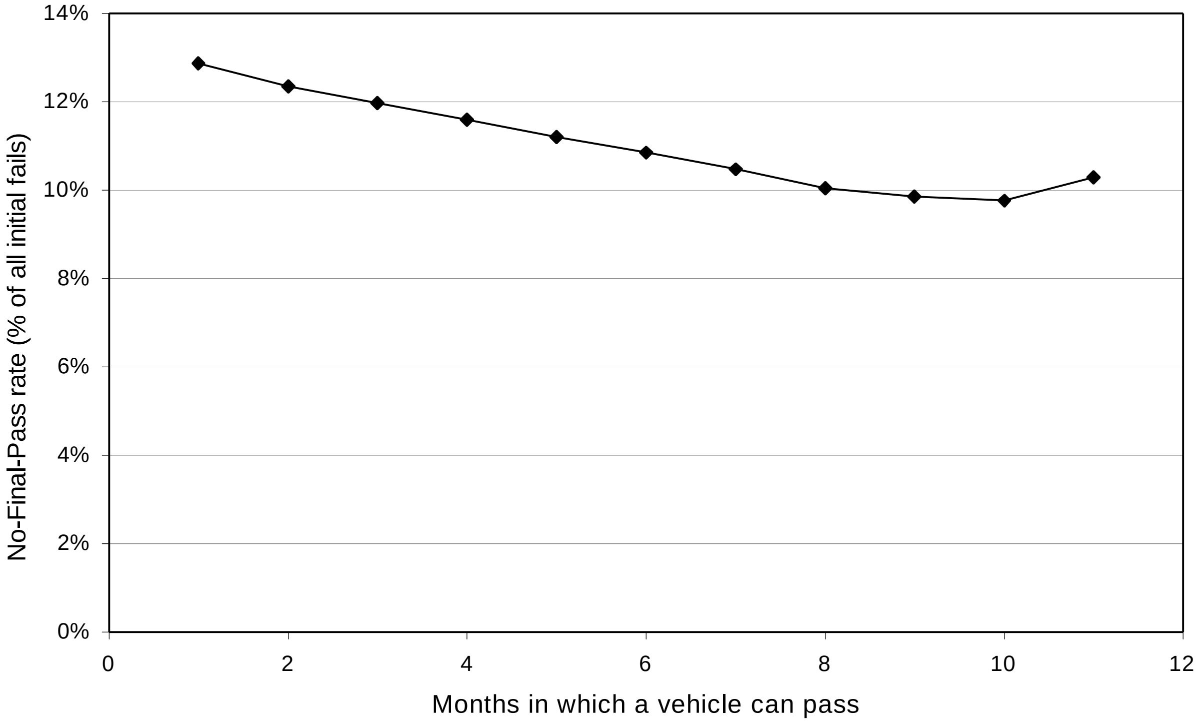
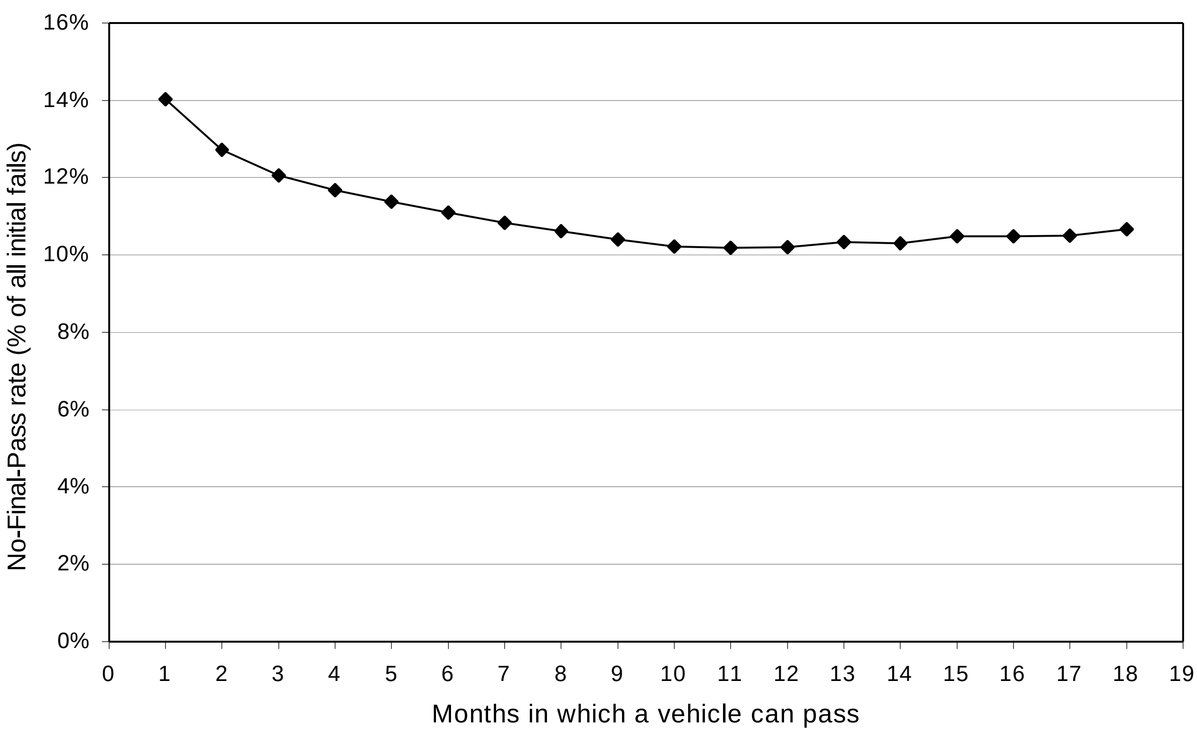
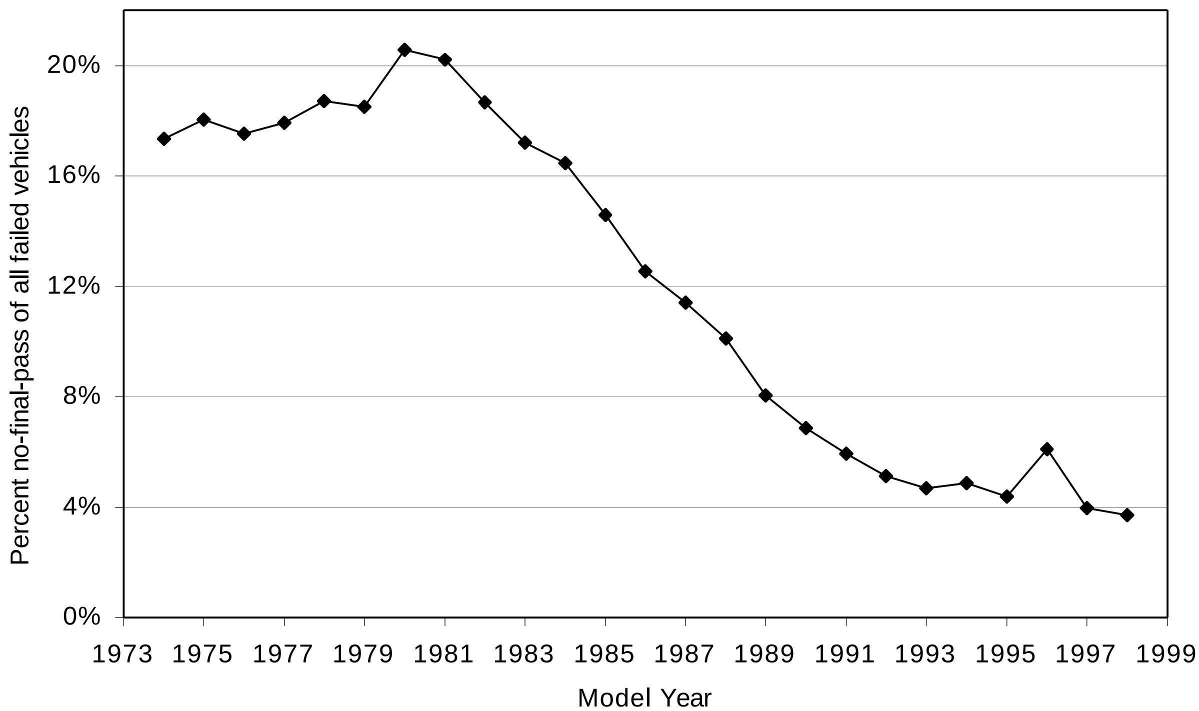


Figure B-2. No-Final-Pass rate by months of data, 18 months



increase slightly after 12 months; this may be due to cutpoint changes that occurred over the 18-month period.) Figure B-3 indicates that the no-final-pass rate is highest for older vehicles, peaking at the 1981 model year and decreasing rapidly for newer vehicles.

Figure B-3. No-Final-Pass Rate by Model Year



To make sure that we were not over-estimating the no-final-pass rate, we analyze two possible reasons for over-counting them. First, it is likely that the owners of some of the no-final-pass vehicles received a repair cost waiver or economic hardship extension, and have up to two years to repair their vehicle. Waived vehicles are not identified in the VID database; however, BAR reports that only 5,000 vehicles received waivers or extensions over the 18 months of the program we analyzed. These vehicles represent less than 1% of all failed vehicles, and 4% of all no-final-pass vehicles.

We attempted to match no-final-pass vehicles with a passing test for a vehicle with a different A second reason that no-final-pass vehicles may be over-counted is that they may have received a passing test while appearing to be a different vehicle in the database. One way for this to occur is that the final passing test of a vehicle has a different vehicle identification number (or VIN) than the initial failing test. The VID database does not code initial tests or have any other indication of how many tests a given vehicle may have had. In our analyses we match test records by VIN to identify multiple tests of the same vehicle. We attempt to match no-final-pass vehicles with a passing test for a vehicle with a different VIN but the same license plate. Using this method, we find that there are as many as 5,500 no-final-pass vehicles that become final-pass vehicles based on a matching license plate.

If we exclude all vehicles that received a waiver or extension, and account for passing tests matching on license, there are 10,600 fewer no-final-pass vehicles. This lowers our estimate of the no-final-pass rate slightly, from 10% to 9% of all vehicles failing their initial test.

15% of all Gross Polluter vehicles received a passing test at a regular Test-and-Repair station, with no record of a subsequent passing test at a Gross Polluter Certification (GPC) or Test-Only station. We classify these vehicles as fail-pass vehicles, because they passed their last Smog Check test, even though that passing test was not at a Test-Only or GPC station, as required. These vehicles represent 3.3% of all vehicles that failed their initial test.

Some of these no-final-pass vehicles may no longer be operating in the Enhanced areas, perhaps because they could not meet Smog Check requirements. The removal of these vehicles, and some of their emissions, from the Enhanced areas is a benefit of the program. However, some of these vehicles may still be driven in Enhanced areas. Our estimate of program benefits, described in Section 4, assumes that two-thirds of no-final-pass vehicles are removed from Enhanced areas, and replaced with the average vehicle. This assumption is based on our estimate that one-third of no-final-pass vehicles continue to be driven in Enhanced areas one year after their Enhanced Smog Check. We describe the reasoning behind this assumption below.

We use the roadside and remote sensing data to estimate the number of no-final-pass vehicles that are driving in Enhanced areas at different time periods since their last Smog Check test. Tables B.1 and B.2 show the fraction of the no-final-pass vehicles in the roadside Untested and Tested fleets, by the time since their previous Smog Check. The top panel of each table shows the number of vehicles in each fleet, by Smog Check result and the number of months since their previous Smog Check. The middle panel of each table shows the fraction of the roadside fleet seen at each time period that were no-final-pass vehicles, expressed as percent of *all* vehicles. The bottom panel shows the fraction of no-final-pass vehicles expressed as the percent of all *failing* vehicles.

In Table B.1, 0.9% of the Untested roadside fleet with a roadside test within three months of their previous Basic Smog Check test were no-final-pass vehicles; this rate drops steadily to 0.3% of the roadside fleet tested nine to 12 months after their Basic Smog Check test. 0.3% of the roadside fleet corresponds to 23% of the fraction of all vehicles that did not receive a passing test in the VID data (1.3% of all vehicles). The bottom panel of Table B.1 indicates that the no-final-pass rate of the Untested roadside fleet measured nine to 12 months after their Basic Smog Check test is 3.5% of all *failing* vehicles; this rate is 35% of the VID no-final-pass rate (10% of all *failing* vehicles). Therefore Table B.1 estimates that 23% to 35% of vehicles with a roadside test nine to 12 months after their Basic Smog Check test are no-final-pass vehicles.

Table B.1. Fraction of no-final-pass vehicles in Untested roadside fleet observed on-road, by time since previous Smog Check

	Months since previous Smog Check			
	0 to 3	3 to 6	6 to 9	9 to 12
Vehicles by Smog Check result				
Initial pass	1,337	1,566	1,626	1,796
Fail-pass	131	125	138	165
No-final-pass	14	8	7	6
Total	1,482	1,699	1,771	1,967
Percent no-final-pass of total	0.9%	0.5%	0.4%	0.3%
Fraction of VID rate (1.3% of all vehicles)	73%	36%	30%	23%
Percent no-final-pass of fails	9.7%	6.0%	4.8%	3.5%
Fraction of VID rate (10% of all fails)	97%	60%	48%	35%

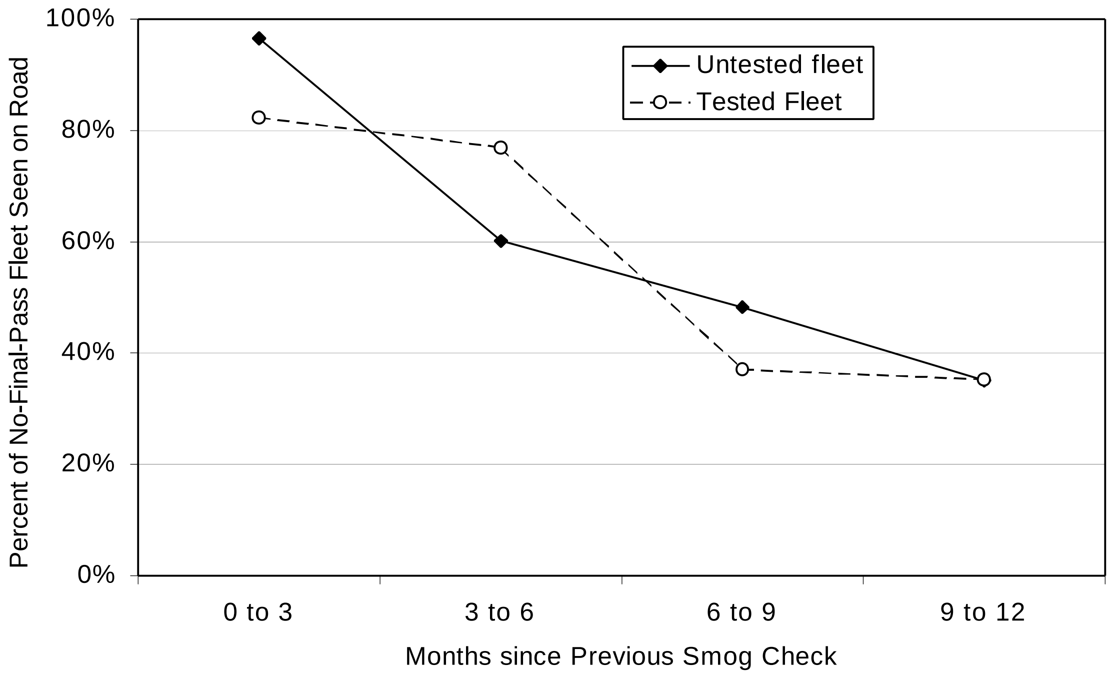
Table B.2. shows the same data for the Tested roadside fleet. The table indicates that 35% to 45% of vehicles with a roadside test nine to 12 months after their Enhanced Smog Check test are no-final-pass vehicles.

Table B.2. Fraction of no-final-pass vehicles in Tested roadside fleet observed on-road, by time since previous Smog Check

	Months since previous Smog Check			
	0 to 3	3 to 6	6 to 9	9 to 12
Vehicles by Smog Check result				
Initial pass	1,112	892	690	431
Fail-pass	234	156	130	82
No-final-pass	21	13	5	3
Total	1,367	1,061	825	516
Percent no-final-pass of total	1.5%	1.2%	0.6%	0.6%
Fraction of VID rate (1.3% of all vehicles)	118%	94%	47%	45%
Percent no-final-pass of fails	8.2%	7.7%	3.7%	3.5%
Fraction of VID rate (10% of all fails)	82%	77%	37%	35%

Both Tables B.1 and B.2 indicate that the no-final-pass vehicles are steadily being removed from Enhanced areas. Figure B-4 graphically shows that the fraction of the no-final-pass fleet observed on road decreases steadily over time. More on-road data are needed to determine what how many of these vehicles continue to be driven in Enhanced areas more than one year after Smog Check. The Tables B.1 and B.2 and Figure B-4 also suggest that the removal rate over time of no-final-pass vehicles from the Untested fleet is similar to that of no-final-pass vehicles from the Tested fleet. This suggests that the Enhanced program has had little effect on the rate of no-final-pass vehicles that continue to be driven in Enhanced areas.

Figure B-4. Percent of No-Final-Pass Fleet Observed on Road, by Months since Previous Smog Check



From this analysis we conclude that about one-third of no-final-pass vehicles are still being driven in Enhanced areas one year after their previous Smog Check test. This degree of program non-compliance is better than observed in the Phoenix I/M program, where 26% of the vehicles that failed initial testing never received a passing test. These vehicles had between three and 15 months to complete I/M requirements. Remote sensing data indicate that half of these vehicles continued to be driven in the Phoenix area more than two years later.[3]

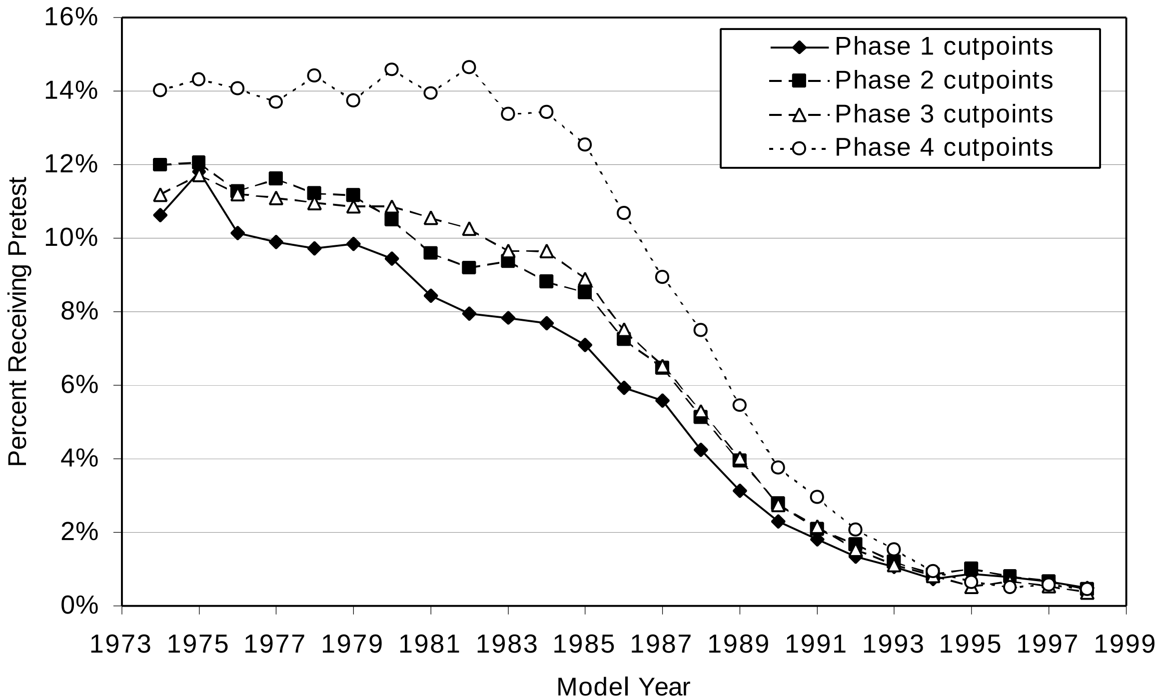
B.3.2. Effect of pretests (official and unofficial)

The extent to which vehicles are repaired or adjusted prior to official testing will increase the effectiveness of the program in reducing emissions. Our estimates of initial program effectiveness include the benefit of repairs or adjustments made after official pretests. Over 18 months, 4.2% of vehicles receive a recorded pretest prior to the official initial test. More older vehicles receive pretests than newer vehicles: 11% of 1974 receive pretests, while only 1% of 1998 vehicles receive pretests. Figure B-5 shows the fraction of vehicles in each model year that receive a pretest, by cut point phase. The figure demonstrates how the fraction of vehicles receiving pretests has increased as the NOx cut points have become more stringent.

---

3. Wenzel, Tom, *Using Program Test Result Data to Evaluate the Phoenix Smog Check Program, Report to the Arizona Department of Environmental Quality*, November, 1999.

Figure B-5. Percent of Vehicles Receiving Pretest, by Model Year
and Cut Point Phase



Overall, only 1% of vehicles receiving a pretest fail their initial official (post-pretest) test. We compare vehicles tested over 18 months of VID data, first including pretests and then excluding pretests, to demonstrate the effect of pretests on failure rates and average initial emissions. The overall program failure rate is 12.6% when pretests are included. However the official failure rate is only 10.5%, after pretests are excluded. Figure B-6 shows the failure rate by model year and cut point phase when pretests are included, while Figure B-7 shows the official failure rates after excluding pretests.

Figure B-6. Overall Failure Rates by Model Year and Cut Point Phase
Including official pretests

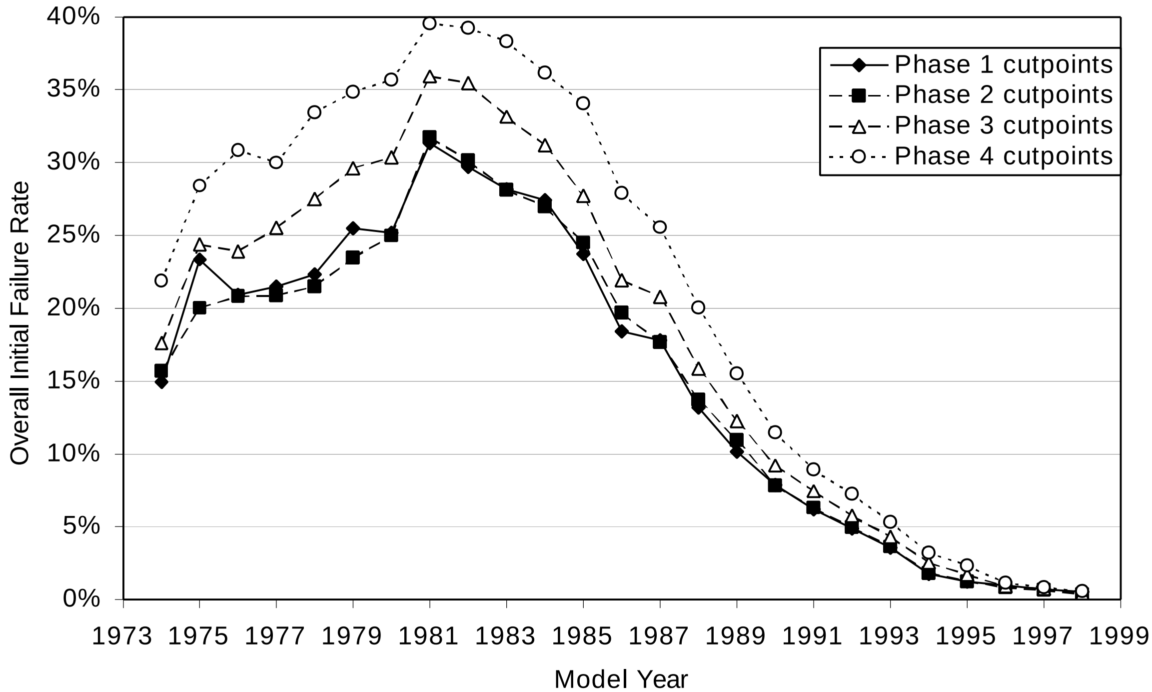


Figure B-7. Overall Failure Rates by Model Year and Cut Point Phase
Official tests only

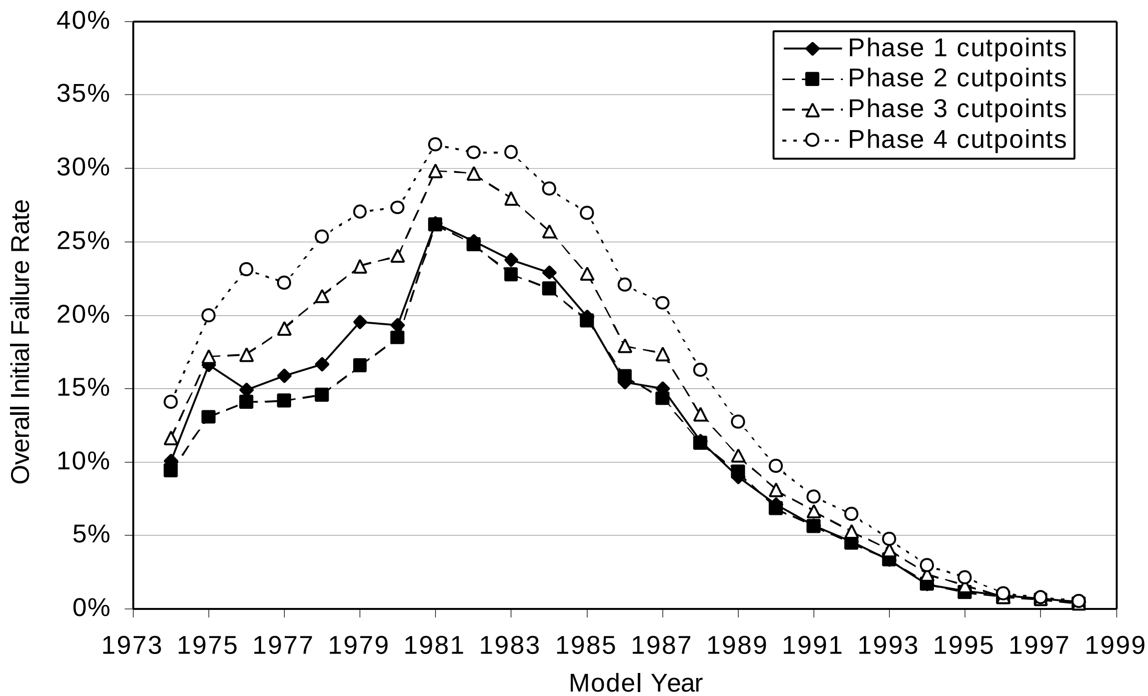


Figure B-8 shows the distribution of vehicles by model year and Smog Check failure mode under Phase 3 cut points, including official pretests. The figure indicates that the overall failure rate (including failing gross polluter cut points and for tampered components) for 1982 vehicles is 35%; 10% of all 1982 vehicles fail gross polluter cut points, and 6% fail for tampered components. The figure shows that 1981 vehicles have the highest failure rate under all three failure modes, that failure rates decline dramatically for newer vehicles, and that virtually no 1991 and newer vehicles fail gross polluter cut points or fail for tampered components. Figure B-9 shows the official test results for these vehicles, after any repairs that may have been done after the pretests. The figure shows that pretest repairs result in a large reduction in failure rates for vehicles that receive an official pretest: less than 2% of 1982 vehicles that received a pretest fail their first official Smog Check test.

Figure B-8. Percent of Vehicles, by Model Year and Result
Includes official pretests

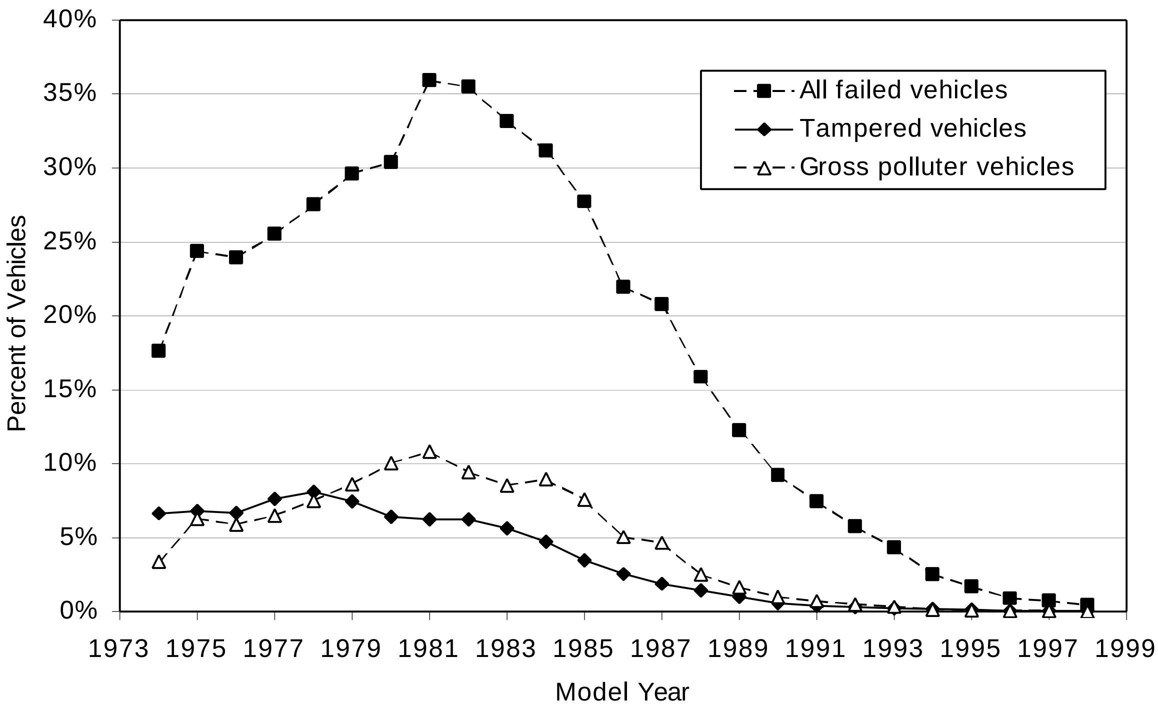


Figure B-9. Percent of Vehicles Receiving Pretest, by Model Year and Official Result

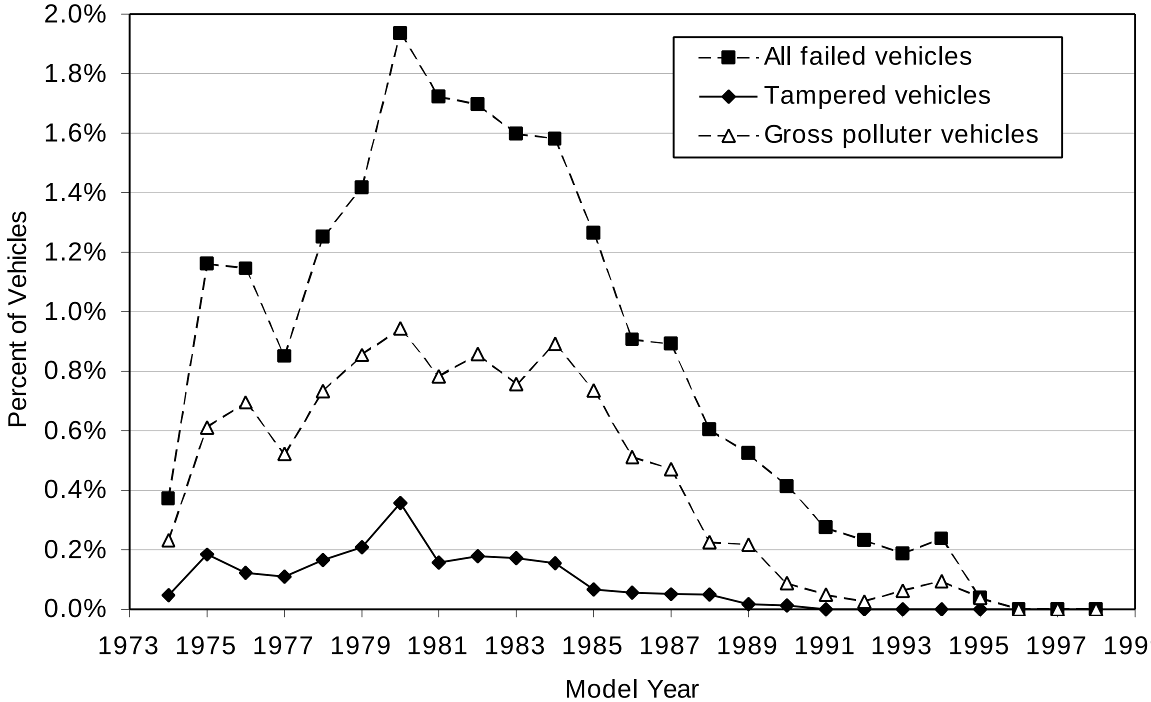


Table B-1 shows that the official initial test emissions as reported in the VID are lower than the emissions when pretest results are included. The table indicates that repairs performed after official pretests account for 6% of the overall reduction in HC, 2% of the reduction in NOx, and 14% of the reduction in CO, as reported in the VID.

Table B-1. Comparison of fleet average emissions over 18 months, including and excluding official pretests

	Including Pretests			Excluding Pretests			
Pollutant	Initial	Final	Redn	Initial	Final	Redn	Diff
HC (ppm)	50	41	19%	47	40	15%	-6%
NOx (ppm)	415	374	10%	406	371	9%	-2%
CO (%)	0.29	0.17	40%	0.25	0.17	33%	-14%

Some technicians abort the test, or code the test as an unofficial training test, if they suspect the vehicle will fail Gross Polluter cut points. It is possible that some of the aborted and training tests are in effect “unofficial” pretests. We look at the fraction of aborted tests by station type to estimate the number of vehicles receiving unrecorded/unofficial pretests. Because they do not perform repairs, technicians at Test-Only stations have less incentive to abort a test if they suspect a vehicle will fail Gross Polluter cut points. Therefore we use the abort rate at Test-Only stations as our estimate of the legitimate abort rate; stations with an abort rate higher than observed at Test Only stations are assumed to be the result of unofficial pretests.

Figure B-10 shows the fraction of all tests that are aborted by station type and model year. The abort rate is fairly steady for older vehicles, until 1988 vehicles, when the abort rate begins to decrease. The abort rate increases for 1996 and newer vehicles; we do not have an explanation for this increase. (These vehicles were exempted from testing through 1999, unless they were sold or were brought into California from another state.) Regular Test-and-Repair stations have the highest abort rate, while Test Only stations have the lowest abort rate. Overall, 6% of all tests at Test-Only stations are aborted, while 12% of all tests at Test-and-Repair stations are aborted (these fleet average abort rates for each station type were calculated using the same model year distribution). Therefore, we estimate that 6% of the tests at Test-and-Repair stations are unofficial pretests that are aborted before completion. Figure B-11 shows that our estimated unofficial pretest rate using aborted tests varies by model year, and by cut point phase.

Figure B-10. Percent Aborted Tests by Station Type and Model Year

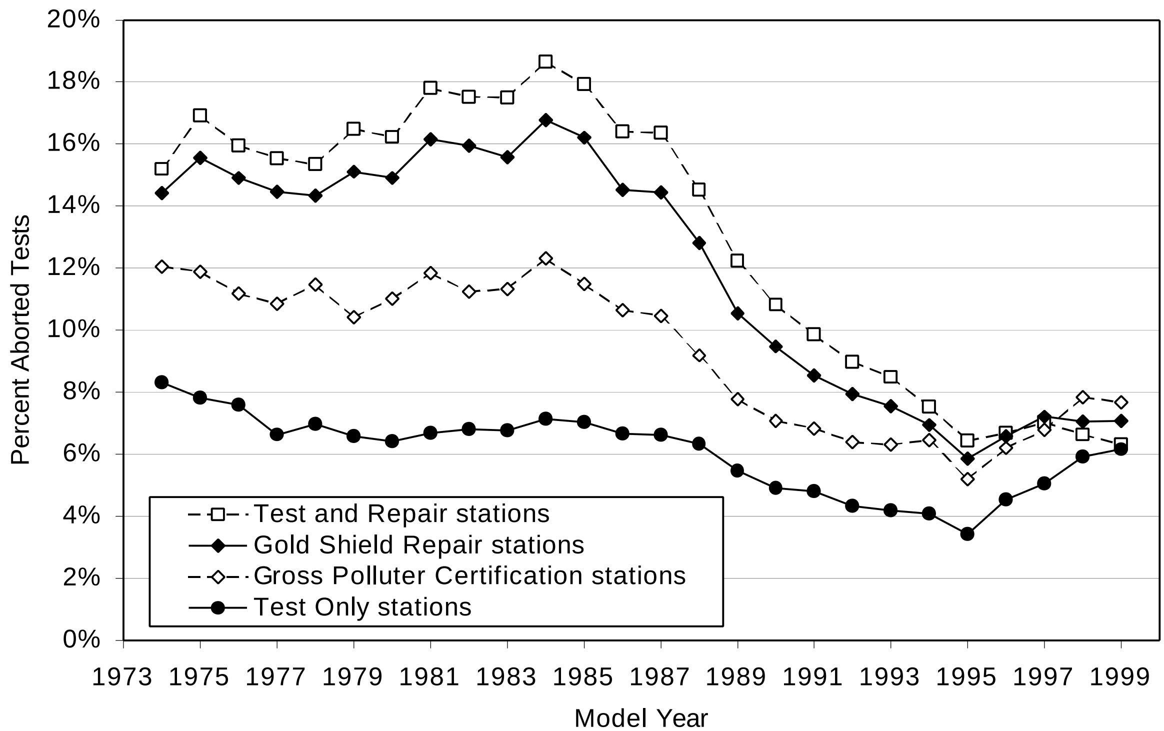
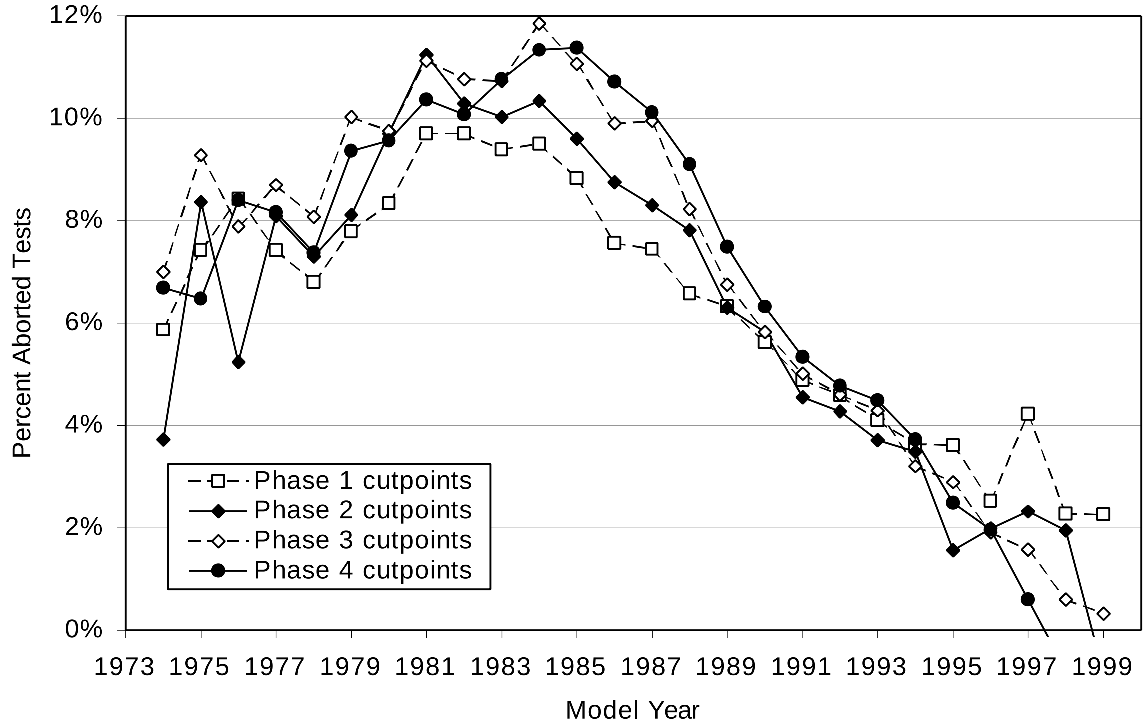


Figure B-11. Estimated Unofficial Pretests by Cut Point Phase and Model Year



Figures B-12 and B-13 show the abort rate by model year and cut point phase, for Test Only (Figure B-12) and regular Test-and-Repair (Figure B-13) stations. The figures indicate that the abort rate has decreased over time, as the NOx cut points have been made more stringent. This suggests that technicians are learning how to properly perform tests over time, without having to abort a test that has been done improperly. The reduction in abort rates over time appears to be greater for Test Only than Test-and-Repair stations. This may perhaps be the result of more close monitoring of these stations by BAR over time.

Figure B-12. Percent Aborted Tests at Test Only Stations
by Cut Point Phase and Model Year

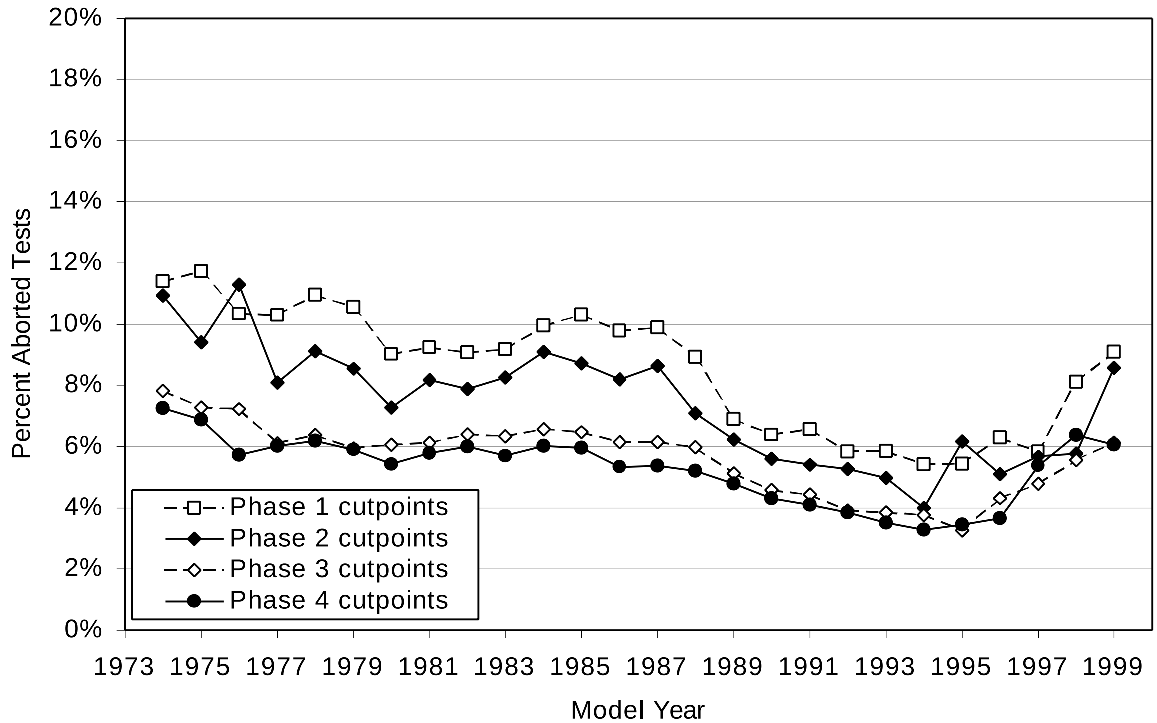
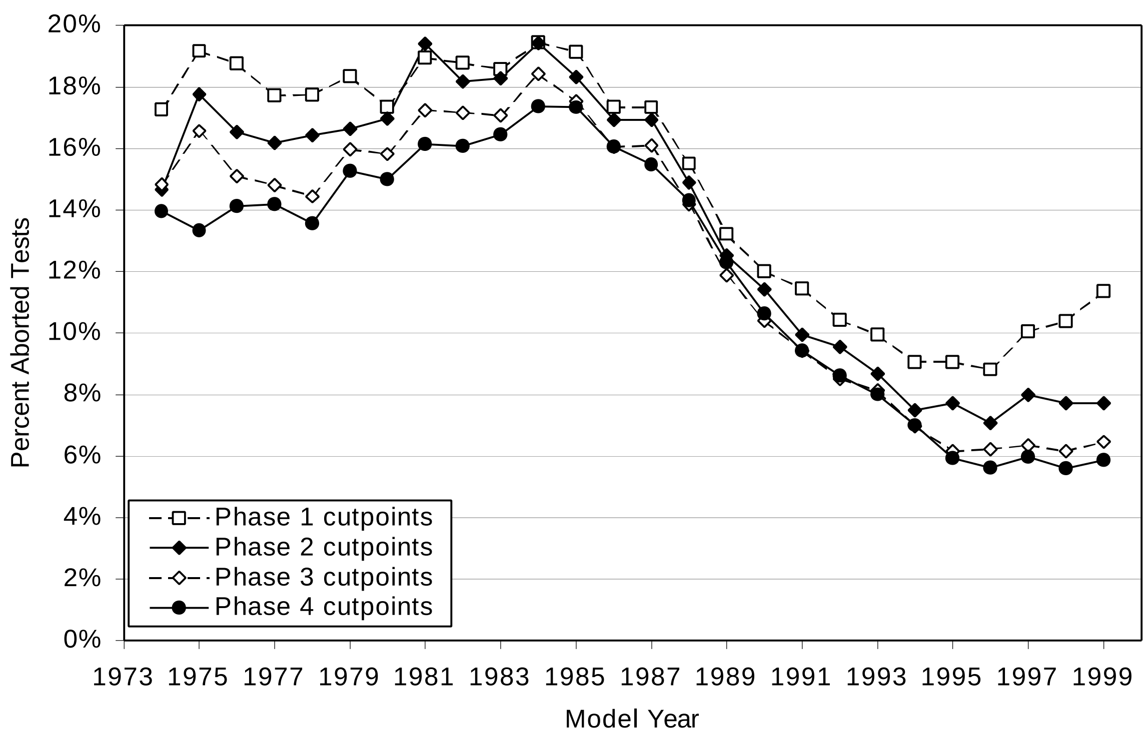


Figure B-13. Percent Aborted Tests at Test & Repair Stations
by Cut Point Phase and Model Year



In addition, 4% of all non-aborted tests at Test-and-Repair stations are coded as training tests, while less than 1% are so coded at Test-Only stations. Therefore, we estimate that as much as 10% (6% aborted tests plus 4% coded training tests) of vehicles at Test-and-Repair stations receive an unofficial pretest that is either aborted or coded as a training test. (We did not have time to examine the rate of training tests in detail, as we did for aborted test; we hope to do these analyses in the future.)

A portion of vehicles receiving unofficial pretests may receive repairs or adjustments that would reduce their emissions prior to official testing. As discussed in Section 4.4 and Appendix D, we use the roadside data to estimate the benefit of any repairs or adjustments made prior to an official recorded pretest. However, the best way to measure the timing of these repairs, and their effect on emissions, is with an extensive remote sensing measurement program.

B.3.3. Effect of test duration

Vehicles are allowed to pass after as little as 10 seconds of emissions measurement on each mode of the ASM test. If ten consecutive seconds of emissions are below the cut point a vehicle can be passed without being tested for the full duration; this is known as a “fast-pass”. Emissions of some fast-passing vehicles would be lower if they were tested for the full 170 seconds of the ASM test (as vehicles warm up, emissions decrease).

We examine total test duration (ASM plus visual and functional inspections) to estimate the effect of the number of “fast passes” on different groups of vehicles. We assume that groups of vehicles with shorter overall test durations are more likely to have been fast passed than vehicles with longer test durations. Figure B-14 shows average test duration, in seconds, by Smog Check result and vehicle model year. The figure indicates that tests of older vehicles take longer than tests of newer vehicles. We weight all fleet average test durations by the same model year distribution to account for difference in test duration by vehicle age. Overall, tests of passing vehicles take on average 11 minutes; tests of failing vehicles take more time, 13 minutes, with tampered vehicles taking the longest time, 15 minutes. Tests of passing vehicles conducted at Gross Polluter Certification stations take more time (12 minutes) than tests of passing vehicles conducted at Test Only stations (10 minutes); Figure B-15 shows average test durations of passing vehicles by station type and model year. Figure B-16 indicates that tests conducted under current (Phase 4) cut points take only slightly longer than tests conducted under initial cut points.

Figure B-14. Average Duration of Test, by Test Result and Model Year

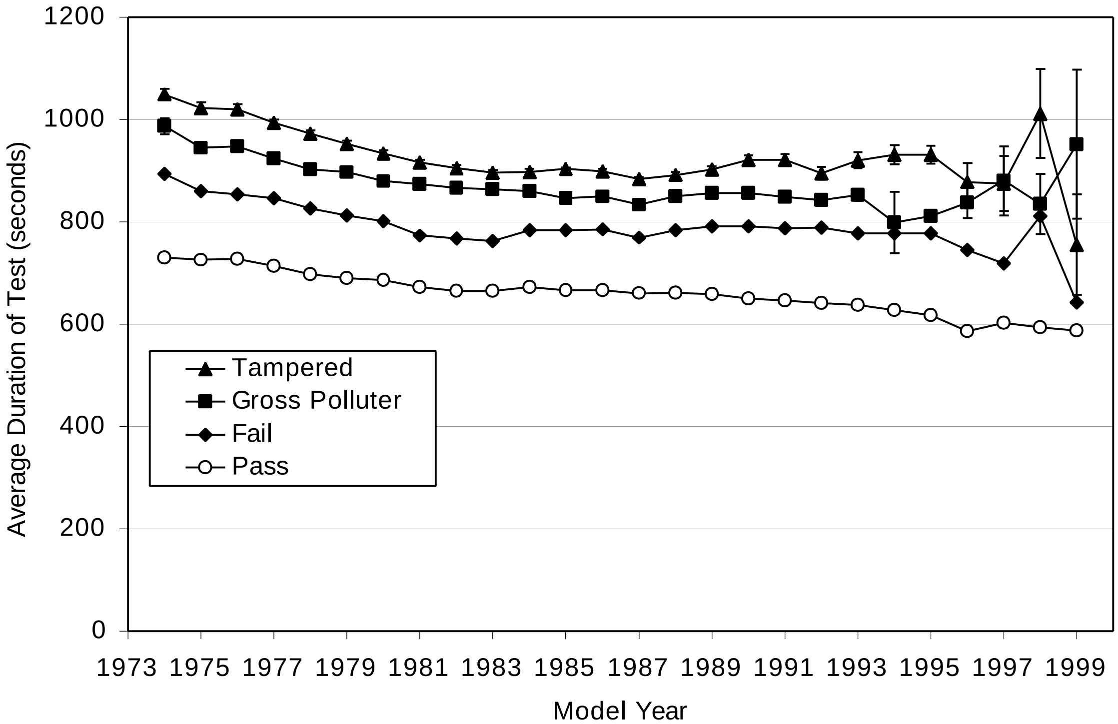


Figure B-15. Average Duration of Passing Tests, by Station and Model Year

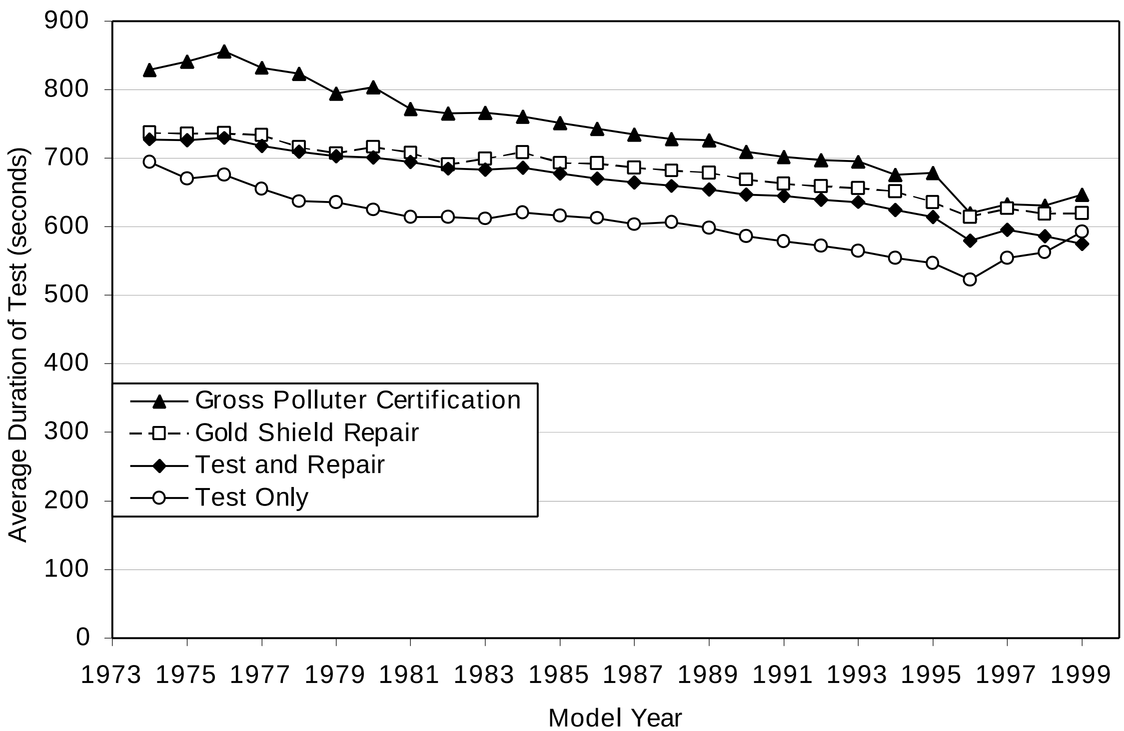
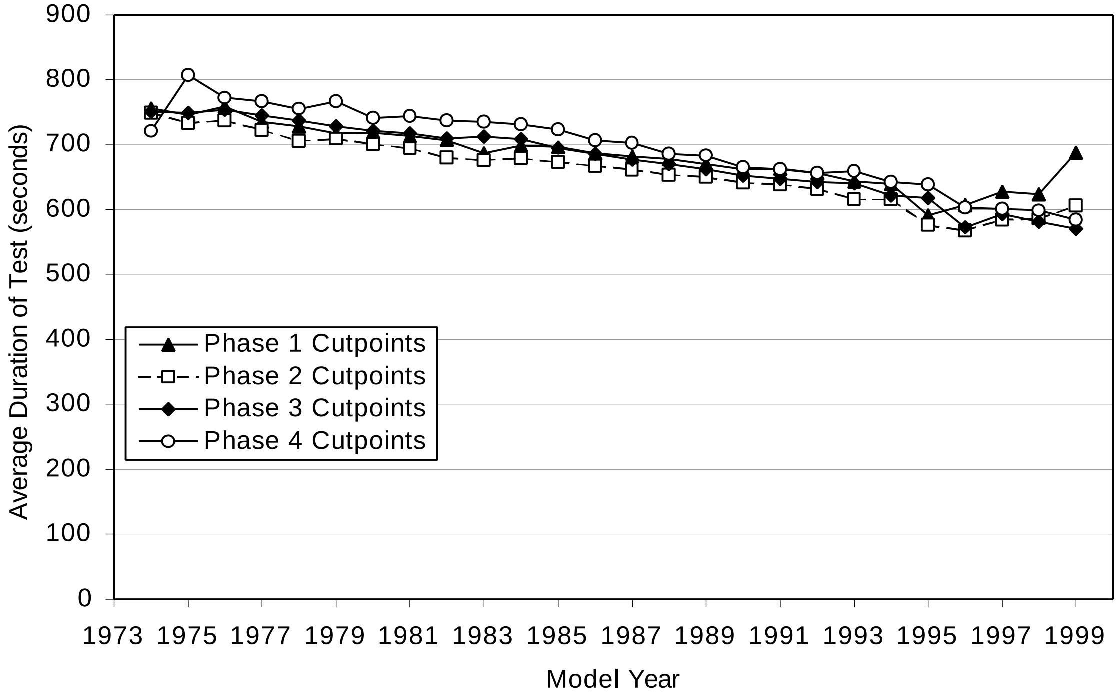


Figure B-16. Average Duration of Tests at Test & Repair Stations
Initially Passing Vehicles by Cut Point Phase and Model Year



The analysis of test duration only indicates which groups of vehicles were likely to have been fast passed. We hope to analyze, in the future, second-by-second Roadside ASM tests to estimate the effect of fast passing of vehicles on the emissions of passing vehicles and the overall fleet.

B.3.4. Days/time to pass

Another factor that may contribute to the effectiveness of the Smog Check program is the speed with which failed vehicles are repaired. Figure B-17 shows that 33% of all fail-pass vehicles pass a retest on the same day as their initial fail (the vertical axis on the figure, showing the cumulative percent of the vehicle fleet, is in logarithmic scale). Of these same-day passes, 28% pass a retest within 30 minutes of the initial test, and 50% pass a retest within an hour (see Figure B-18).

Figure B-17. Distribution of Weeks to Pass, Fail-Pass vehicles

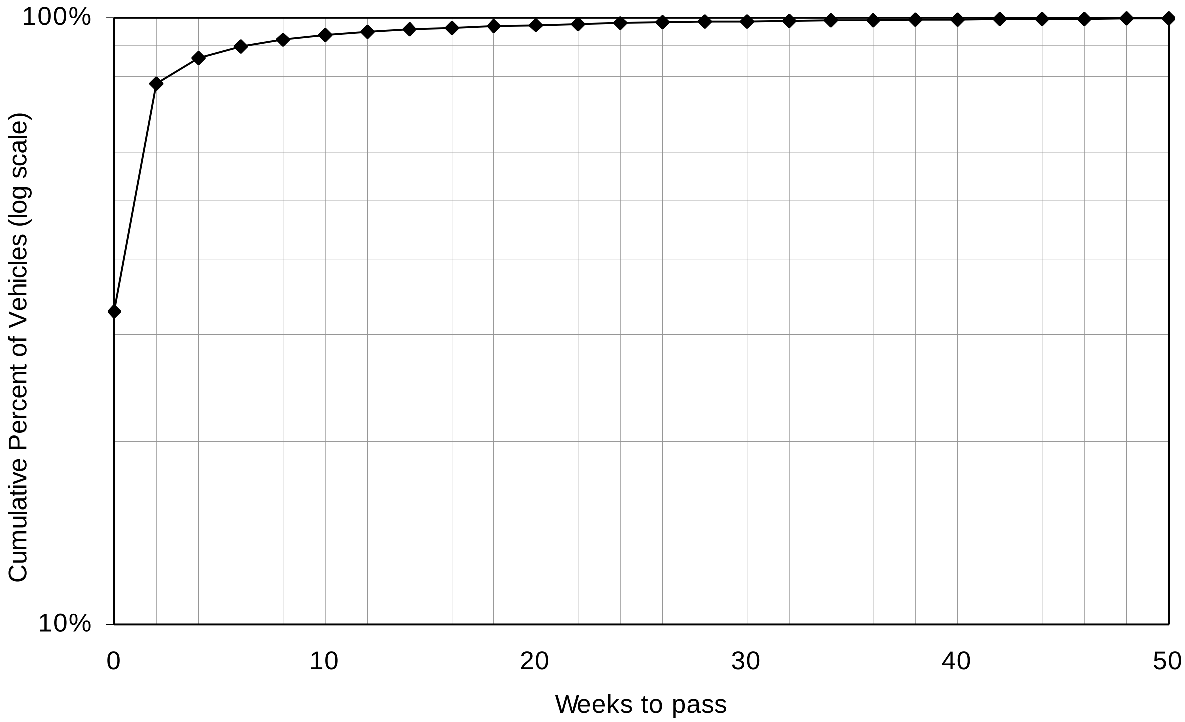


Figure B-18. Distribution of Minutes to Pass, Fail-Pass vehicles
Passing on Same Day

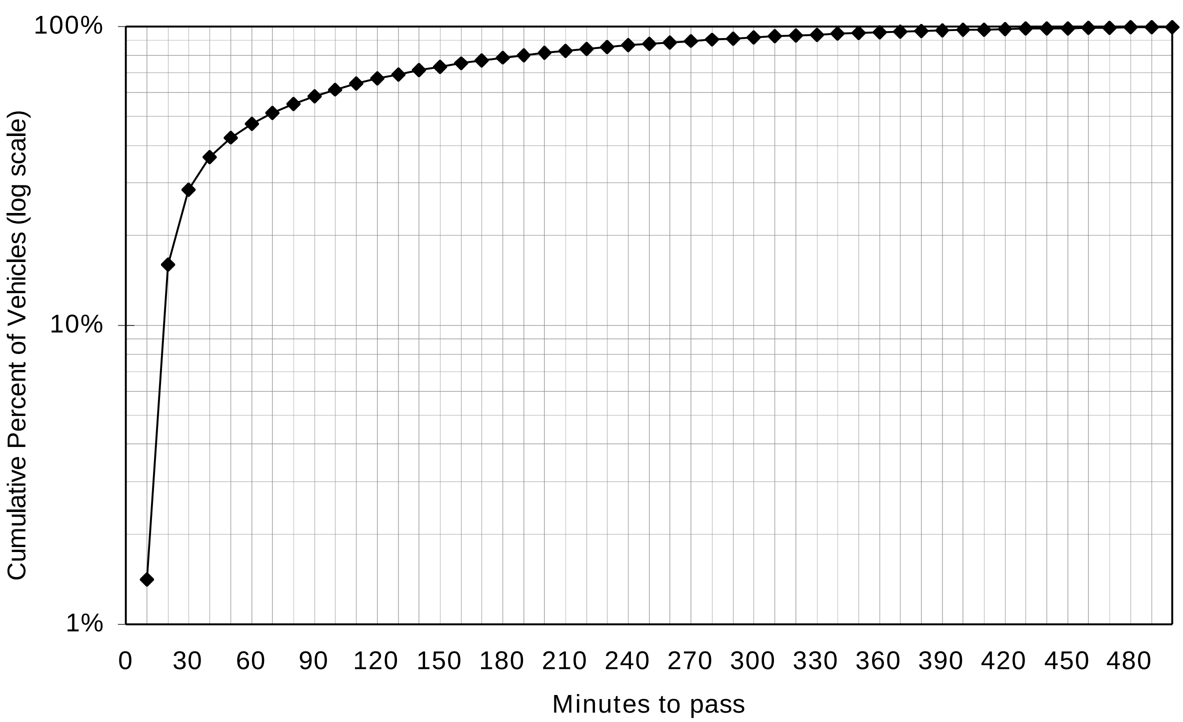
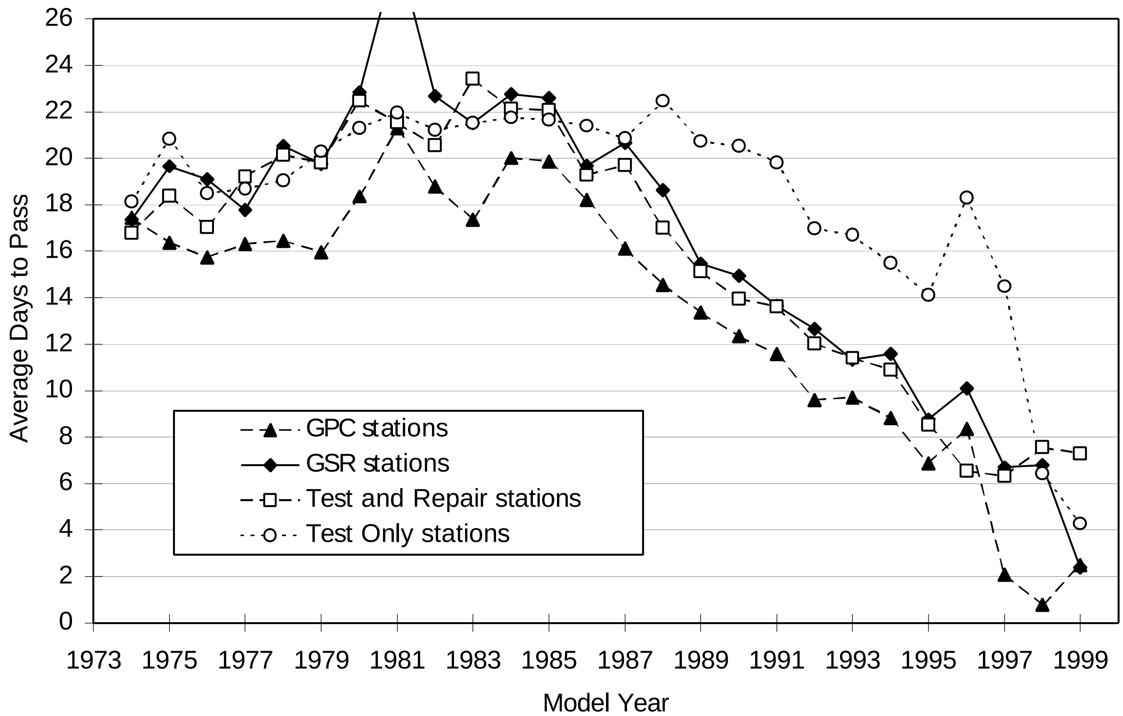


Figure B-17 also indicates that 90% of all fail-pass vehicles have passed a retest within 45 days (or six weeks) of their initial test, 95% have passed within 90 days (13 weeks), and 98% have passed within six months (26 weeks). The average time for a fail-pass vehicle to pass is 19 days. The time it takes to pass after failing an initial test varies by station type. Vehicles that have their final passing test at a Gross Polluter Certification station take on average 15 days to pass, while vehicles that receive a passing test at Test-Only stations take on average 21 days to pass (see Figure B-19). Vehicles that either fail gross polluter cut points or have been tampered take on average 27 days to pass, while vehicles that just fail the emissions test take on average 15 days to pass. Decreasing the days to pass, especially for the gross polluters, would naturally increase the effectiveness of the program. Of course, as discussed in the no-final-pass section, some vehicles never receive a passing retest.

Figure B-19. Average Number of Days to Pass
by Model Year and Station Type



Appendix C. Analysis of multi-cycle program data

As discussed in Section 4, comparing the initial to final test result of individual vehicles will overstate the benefit of the program. As a group, the average emissions of failing vehicles will be lower on a subsequent retest than on their initial test.[4] As a result, some initially failing vehicles will pass their final retest without having been repaired and their emissions reduced. On the other hand, the average emissions of passing vehicles will be slightly higher on an immediate retest, again because of test to test variability. (In addition, if vehicles that pass their first test are not properly warmed up prior to the first test, their emissions would decrease on a subsequent retest when the engine and catalyst are warmed up).

The change-of-ownership testing requirement in California allows us to estimate this effect on initial program effectiveness. About 5% of all vehicles have a second I/M cycle in the 18-month period of data we analyzed; we call these vehicles the "multi-cycle" fleet. We use test records on 69,000 vehicles that were originally tested in the first three months of the Phase 3 cut points (November 11, 1998 to February 11, 1999) to ensure that all vehicles were tested under the same cut points. We limit the analysis to the first three months of Phase 3 cut points to ensure that the fleet of vehicles tested in each time period after their initial test were roughly the same age.

The full benefit of the I/M program should include any lasting reduction in emissions due to vehicles being repaired or adjusted prior to I/M testing. California's program attempts to measure the effect of repairs made prior to the official test, by establishing an official pretest. Pretest emissions results are recorded, but are not used to determine whether a vehicle officially fails a test, or whether it is identified as a gross polluter. To account for at least some repairs made prior to official I/M testing, we base all of our results on all recorded tests, including any pretests (unless specifically stated otherwise). Nevertheless, additional repairs may be performed before the recorded pretest.

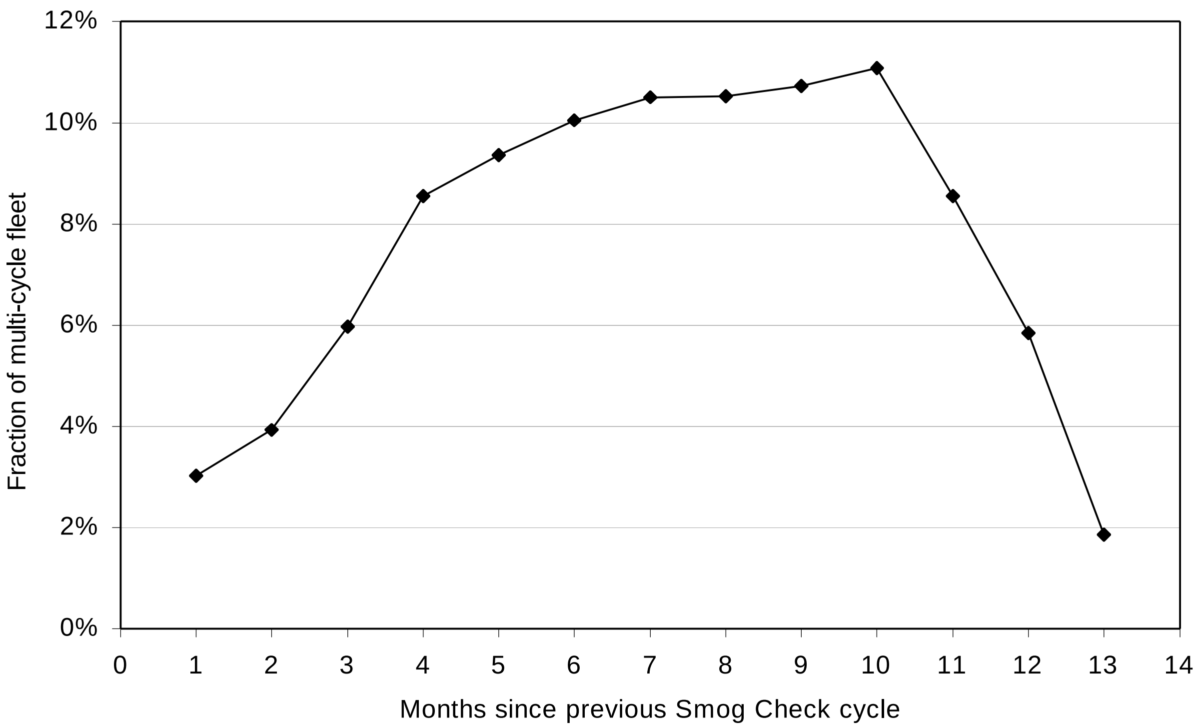
We sort the VID test results of the multi-cycle fleet by vehicle identification number (VIN), test date and test time. (An analysis of the accuracy of the VINs in the VID is included in Appendix B.) Next we determine the initial and last VID test for each unique vehicle. We code each Smog Check cycle separately; for vehicles that failed their initial test we code the first test after the first passing, non-pretest as the initial test of a new test cycle. Gross Polluter vehicles are required to get a passing test at a Test Only or Gross Polluter Certification station. For Gross Polluters, we use the first passing, non-pretest at the correct station type as the end of the initial test cycle. Similarly, we require that all vehicles initially tested at Test Only stations get a final passing test at a Test Only station as well. (Just over half of the vehicles tested at Test Only stations are required to get their test at a Test Only station; therefore we exclude a small number of vehicles that failed their initial test at a Test Only station but eventually were legally certified at a Test-and-Repair station from our database of multi-cycle vehicles.) There were a small number of vehicles that had two passing Smog Check tests on the same day; we exclude these vehicles from our analysis.

---

4. There are three basic reasons for why vehicles may fail an immediate retest: 1) test to test variability of vehicle emissions, particularly for vehicles with emissions near the program cut points and vehicles with intermittent malfunctions; 2) changing environmental or test conditions, such as whether a vehicle was properly warmed up prior to testing; or 3) reporting of passing test results from a known clean vehicle as those from a dirty vehicle (test fraud).

Figure C-1 shows the vehicle distribution of the multi-cycle fleet by the number of months since the initial test of each vehicle's first Smog Check cycle. 3% of the multi-cycle fleet had a second Smog Check cycle up to one month after the initial test of their first cycle, while 4% of the fleet had a second cycle from one to two months after their initial test. A Smog Check certificate is good for 60 days; it is not clear why 7% of the multi-cycle fleet initiated a second Smog Check cycle within 60 days of the first test of their initial cycle. The number of vehicles begins to decrease after 11 months after the initial cycle, because we analyze less than 13 months of test data.

Figure C-1. Distribution of Vehicles by Months since Previous Cycle



We analyze vehicles that fail their initial test but pass a retest (fail-pass fleet) separately from vehicles that passed their initial test (initial pass fleet). As discussed above, we included only those vehicles with an initial test in the first three months of Phase 3 cutpoints. Figure C-2 shows the average vehicle model year of the fail-pass and initial pass fleet, by months since their previous Smog Check cycle. For the most part the average model year of each group of vehicles tested at different times since the last cycle is the same, for both the fail-pass and initial pass fleets. However, the initial pass vehicles tested up to three months after their initial Smog Check cycle are about one year younger than the rest of the initial pass fleet.

Figure C-2. Distribution of Vehicles by Months since Previous Cycle

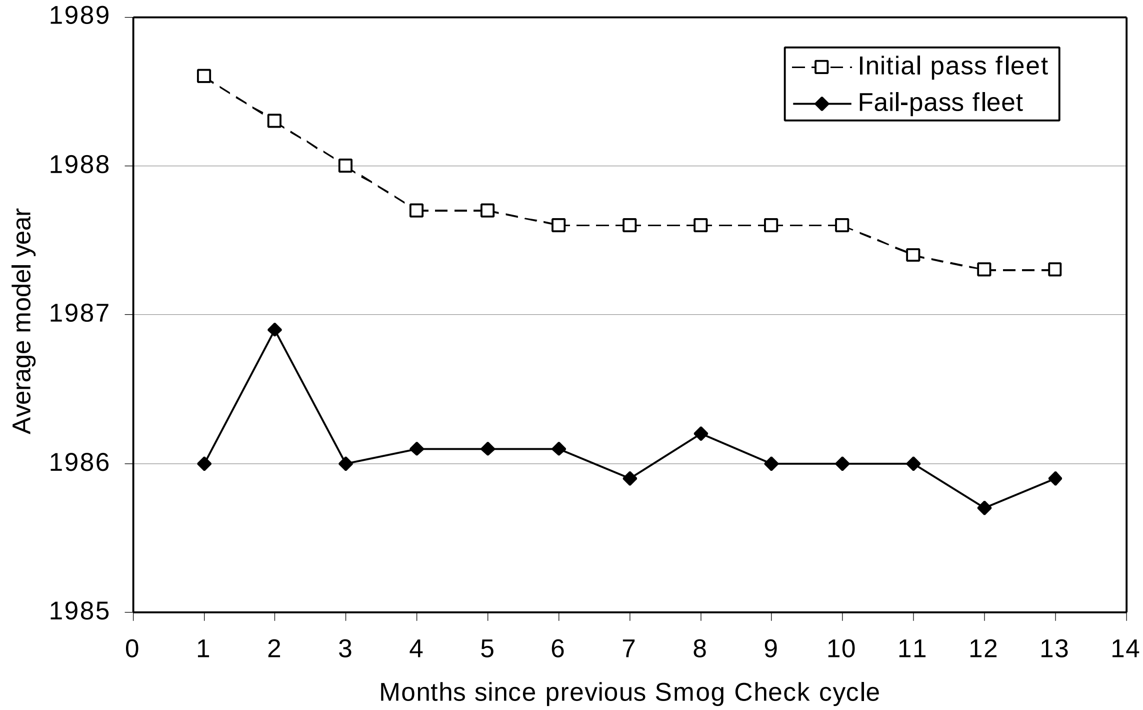


Figure C-3. Failure Rate in Next Cycle by Months since Previous Cycle

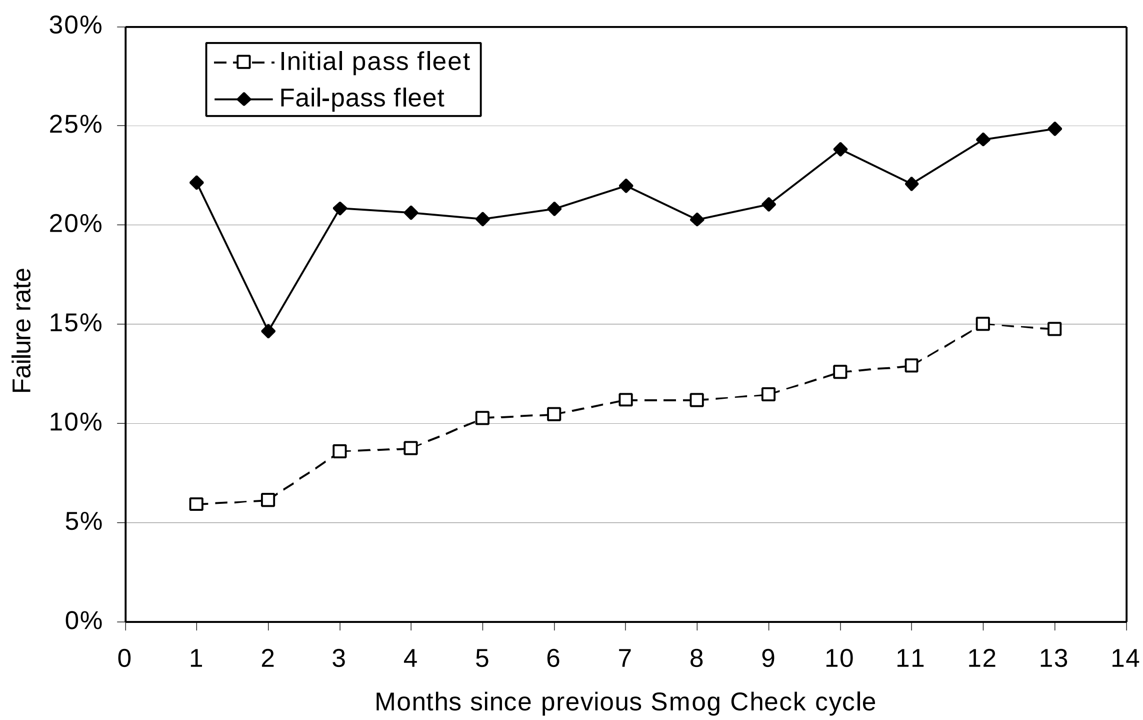


Figure C-3 shows the failure rate on the initial test of the second Smog Check cycle for the fail-pass and initial pass fleets, by time period. The figure indicates that 20% of the fail-pass fleet would fail if retested immediately after their passing test in their first cycle. This failure rate stays steady for about 9 months after the initial test, and does not begin to increase until perhaps 9 months after the initial test. In contrast, about 6% of the initial pass fleet would fail an immediate retest. However, the failure rate of the initial pass fleet increases steadily over time, as more of these vehicles malfunction and become high emitters. Figure C-3 suggests that 10% of the initially passing vehicles would fail a retest 6 months after their initial test, and 15% would fail 12 months later.

Figure C-4 shows the failure rate on the initial test of the second cycle for the fail-pass and initial pass fleets, over all time periods since the previous cycle, by model year. The figure indicates that for both fleets the failure rate is higher for older vehicles than newer vehicles. The second cycle failure rate of the fail-pass fleet is 26% for 1974 to 1984 vehicles, 21% for 1985 to 1989 vehicles, and 15% for 1990 to 1992 vehicles. The failure rate of the initial pass fleet is 19% for 1974 to 1984 vehicles; there is a steady decrease in the failure rate for newer vehicles, from 16% for 1985 vehicles down to 5% for 1992 vehicles.

Figure C-4. Failure Rate in Next Cycle by Model Year

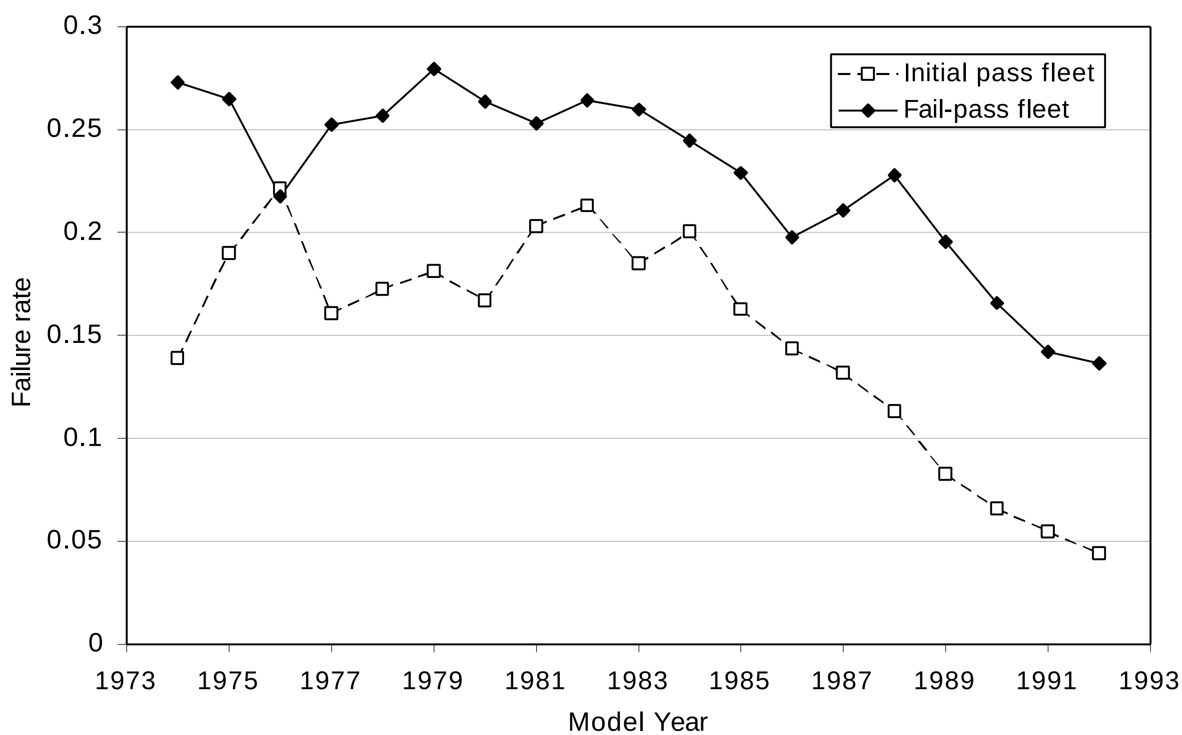


Figure C-3 suggests that 20% of fail-pass vehicles would fail a retest immediately after their passing test. Therefore we use the emissions difference between the initial test on the first cycle and the initial test on the second cycle to estimate the emission reduction from the fleet of fail-pass vehicles. We estimate that emissions of the fail-pass fleet are reduced by 44% for HC and NO, and by 72% for CO, up to 2 months after initial testing. These estimates are shown for each pollutant in Figure C-5 (HC is expressed as C1 in Figure C-5, which is 6 times the HC level measured under the ASM test).[5] A simple comparison of emissions as measured under the initial and final test of the first Smog Check cycle would result in emissions reductions of 59% for HC, 85% for CO, and 46% for NOx, leading to an overstatement of program effectiveness.

Figure C-5. Average Emissions and Emission Reductions of Fail-Pass Vehicles

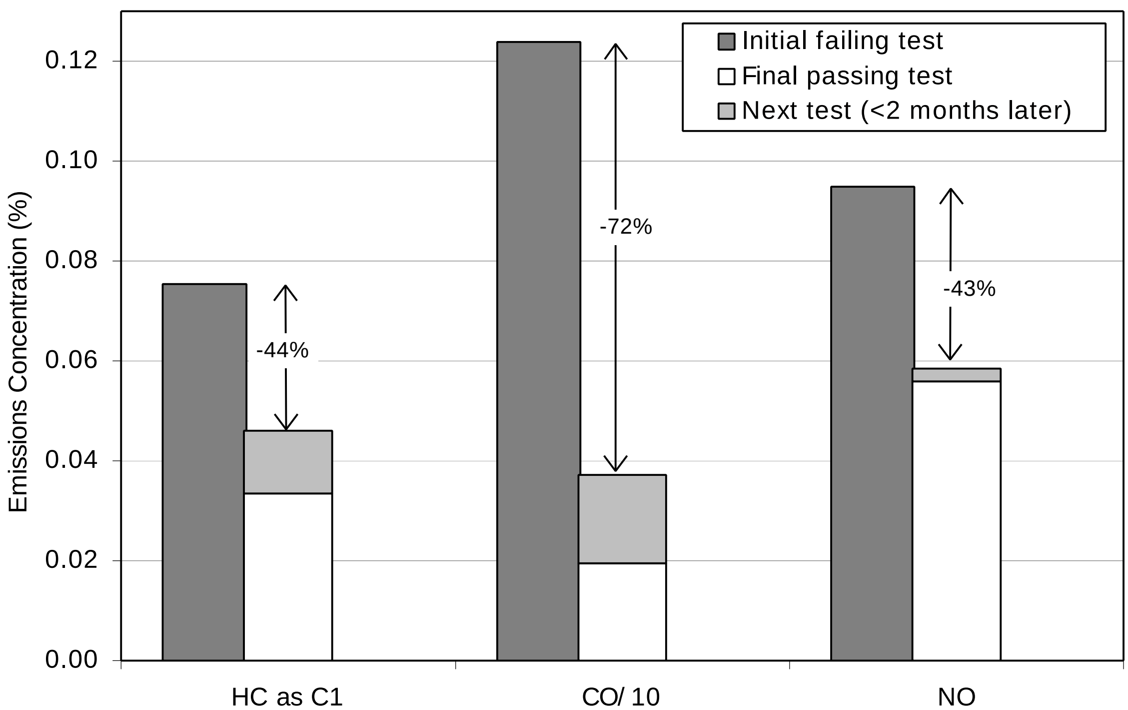


Figure C-6 shows the change in emissions of the fail-pass fleet, relative to the fleet emissions at the initial test at each time period, over time. (Reductions in emissions are represented by negative percentages, while increases in emissions are shown as positive percentages.) Figure C-6 indicates that emissions of the fail-pass fleet are quite steady for about 12 months after initial testing, and perhaps begin to increase only about a year after initial testing. Figure C-7 shows the change in emissions of the initial pass fleet, relative to the emissions of the initial test at each time period, over time. (Increases in emissions are shown as positive percentages.) The HC and CO emissions of the initial pass fleet increase as the fleet gets further from its initial Smog Check test, with HC emissions 30% higher, and CO emissions 70% higher, 6 months after the

5. This may overstate the initial emissions reductions of the program, as the average emissions of the fail-pass fleet, if retested without any repairs, would be lower than as measured on the initial test. We estimate the magnitude of this effect, and the impact it has on emission reduction estimates, in Appendix D.

Figure C-6. Emissions of Fail-Pass Fleet by Months since Previous Cycle

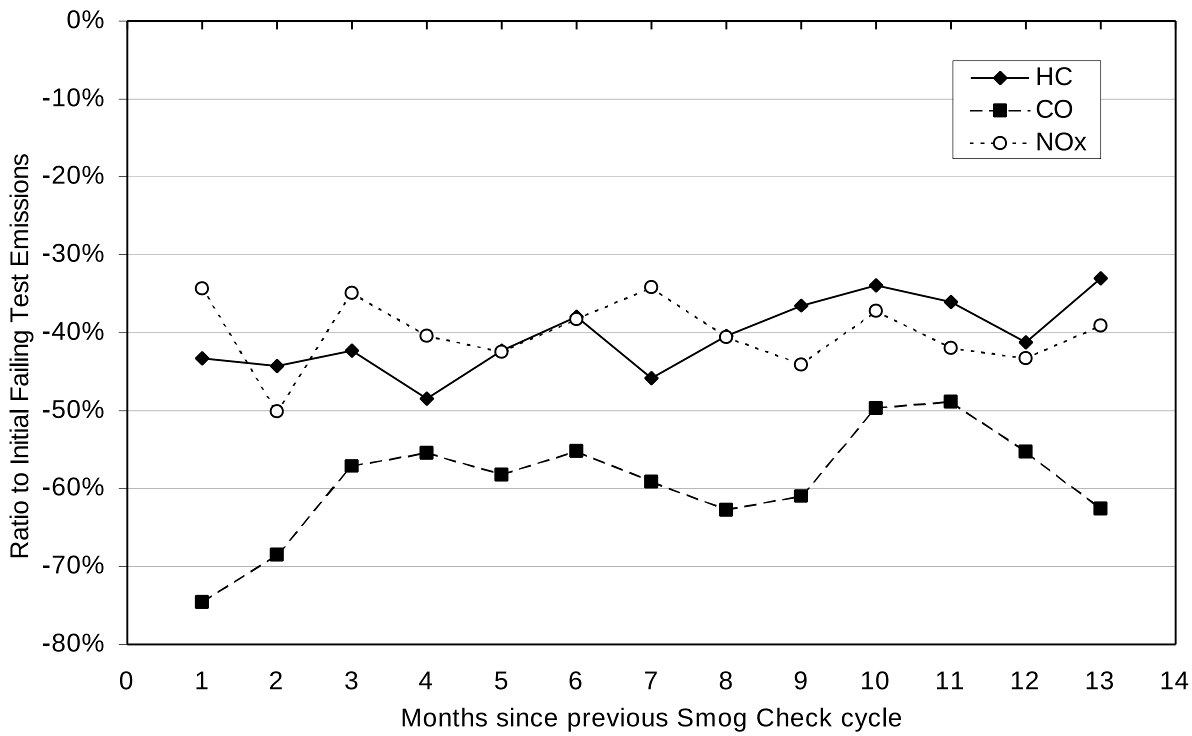
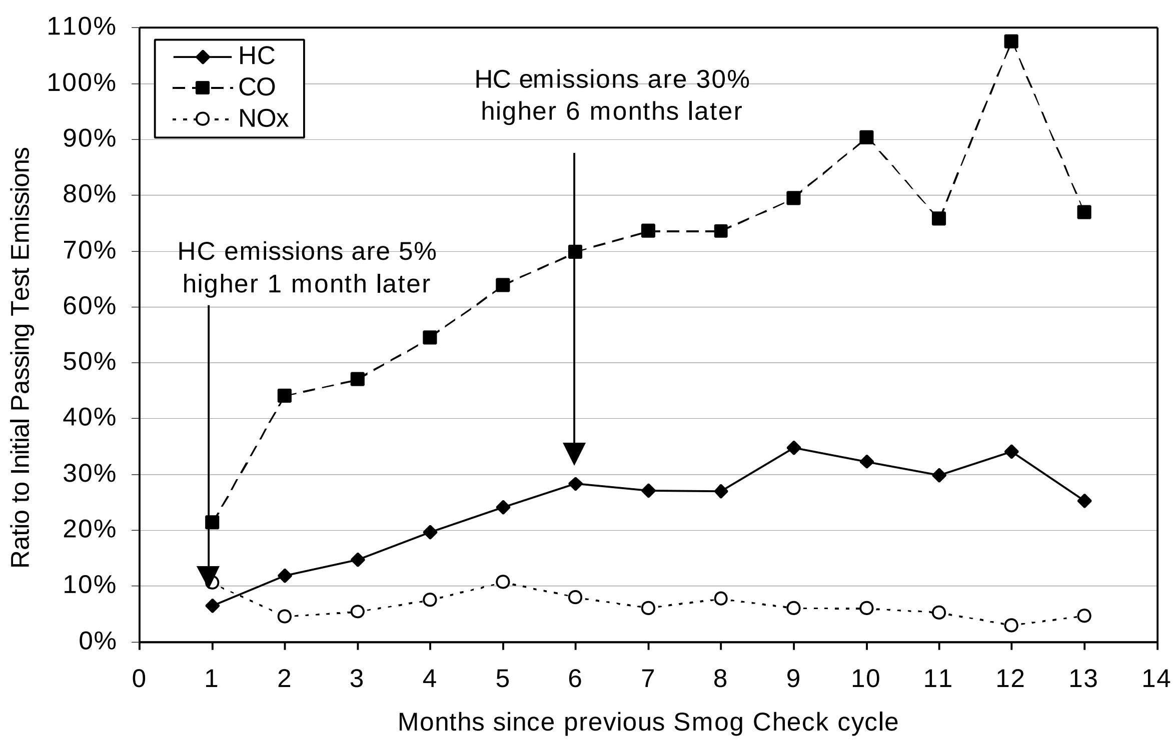


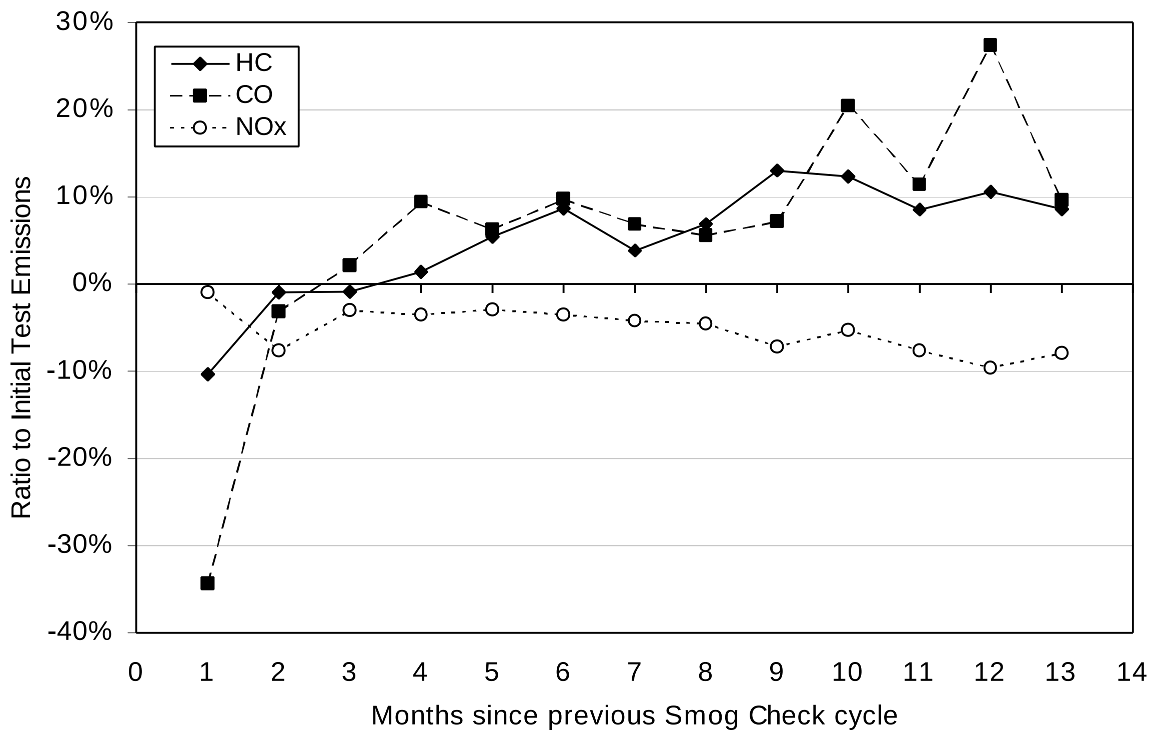
Figure C-7. Emissions of Initial Pass Fleet by Months since Previous Cycle



initial test. HC emissions of the initial pass fleet are fairly steady from 6 to 12 months after initial testing, while CO emissions increase slightly. NOx emissions of the initial pass fleet increase from 2 to 6 months after initial testing, to 10% higher than under the initial test, but then decrease down to 5% higher than the initial test 12 months later. These differences in NOx emissions over time may be because vehicles are being repaired to HC and CO cut points that are relatively more stringent than the current NOx cut points. Some repairs to reduce HC and CO emissions may increase NOx emissions, but not enough to cause the vehicle to fail the relatively loose NOx cut points.

The increase in emissions from the initial pass fleet offsets the stable emissions from the fail-pass fleet, so that the HC and CO emissions of the combined fleet are higher as soon as 4 months after initial testing, as shown in Figure C-8. (Again, emission reductions from initial test emissions are shown as negative percentages, while emission increases from initial test emissions are shown as positive percentages.) This is because the multi-cycle fleet is dominated by initial pass vehicles: 87% of the multi-cycle fleet are initial pass vehicles, and the remaining 13% are fail-pass vehicles. The increase in NOx emissions of the initial pass fleet are much lower than the increase in HC and CO emissions, so that NOx emissions from the combined fleet are lower than initially tested, even 12 months after the initial test. It is important to note that,

Figure C-8. Emissions of Overall Fleet by Months since Previous Cycle



even though fleet emissions are higher four months after initial testing, *they are lower than they would be in the absence of the Smog Check program*. We know this because the emissions of 80% of the fail-pass fleet are reduced from 40% to 60% (depending on pollutant), and these reductions remain steady over the 12 months after initial testing, as shown in Figure C-6. (In reality, the emissions of the overall fleet decrease over time, as older, high emitting vehicles are replaced by newer, low emission vehicles, due to fleet turnover. This effect is not shown in the figures, which portray the change in emissions over time for a fixed fleet of vehicles.)

Figures C-9 through C-11 show the average emissions for the fail-pass and initial pass fleets, by time since the initial Smog Check Test. The fail-pass (FP) fleet is identified by diamonds, the initial pass (IP) fleet by circles. The initial emissions of the first cycle are identified by solid symbols and lines, while the initial emissions of the second cycle are identified by open symbols and dashed lines. The figures also include the final emissions of the first cycle for the fail-pass fleet. The figures show the reduction in emissions from the fail-pass fleet, as measured using the final test of the first cycle and using the initial test of the second cycle. The cycle 1 final emissions of the fail-pass fleet are slightly higher than the initial emissions of the initial pass fleet; this is because the fail-pass fleet is slightly older on average than the initial pass fleet, as shown in Figure C-12. In light of the fact that the overall fleet is dominated by initial pass vehicles, the combined emissions for the overall fleet are very similar to, but slightly higher than, those of the initial pass fleet.

Figure C-9. Average HC 2525 Emissions by Months since Previous Cycle

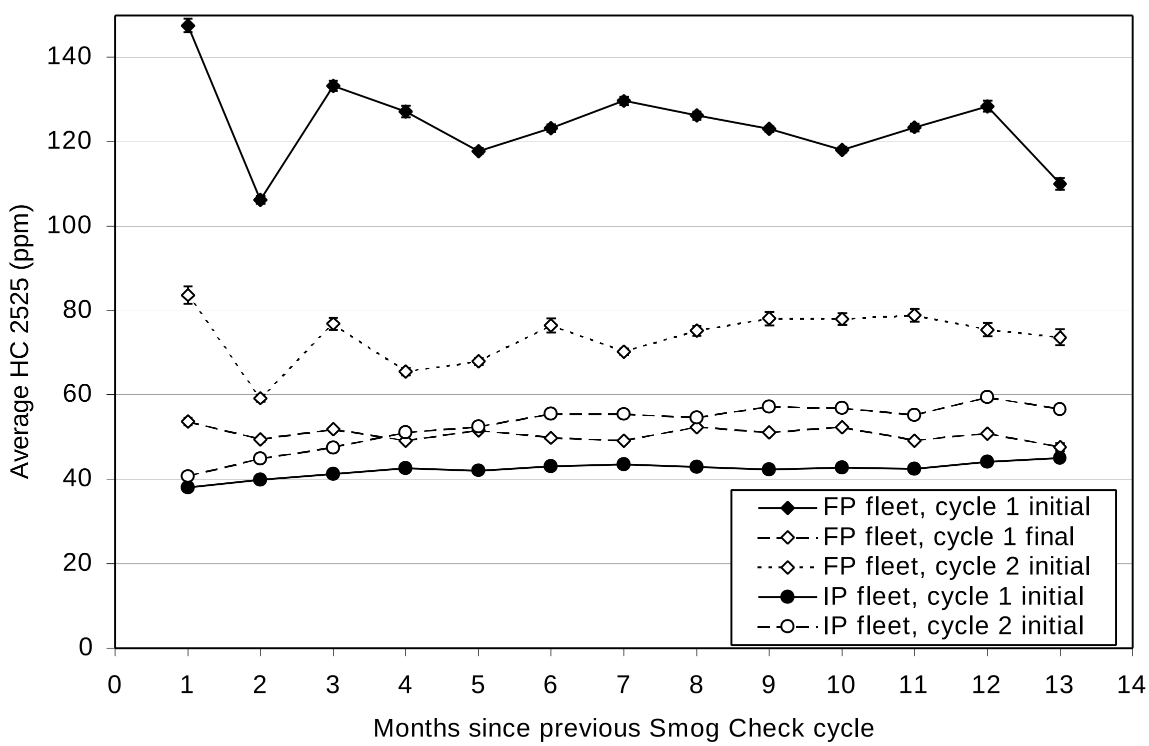


Figure C-10. Average CO 2525 Emissions by Months since Previous Cycle

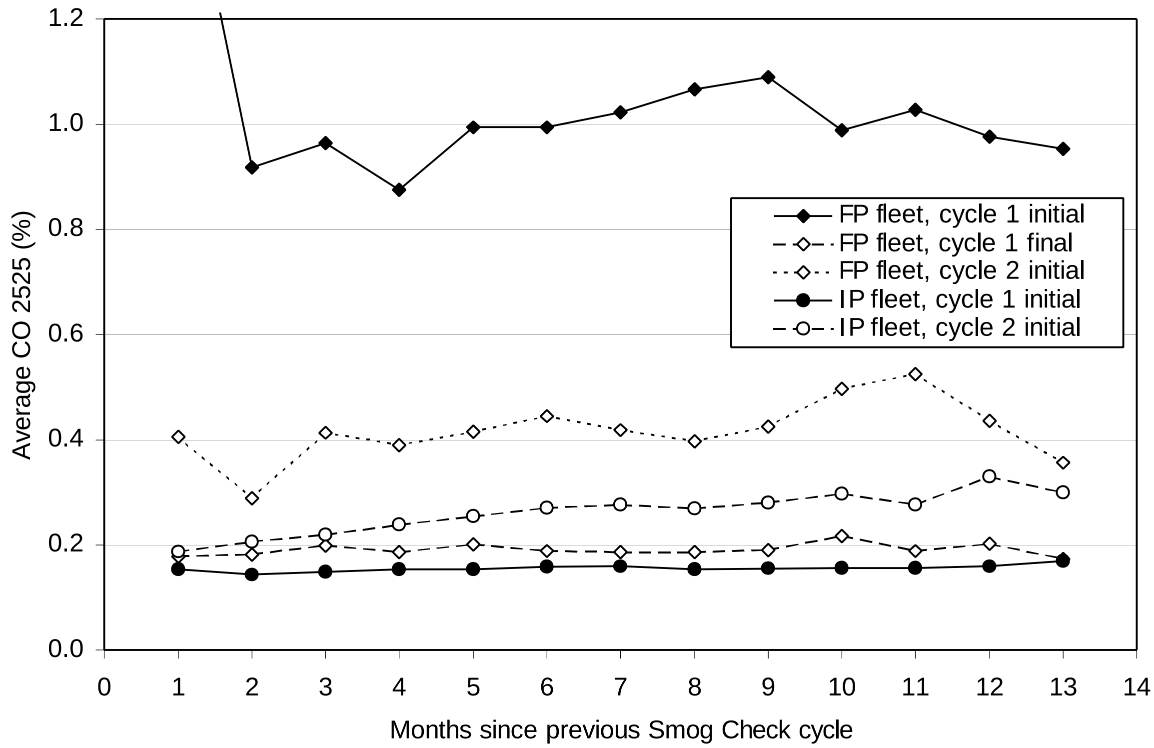


Figure C-11. Average NO 2525 Emissions by Months since Previous Cycle

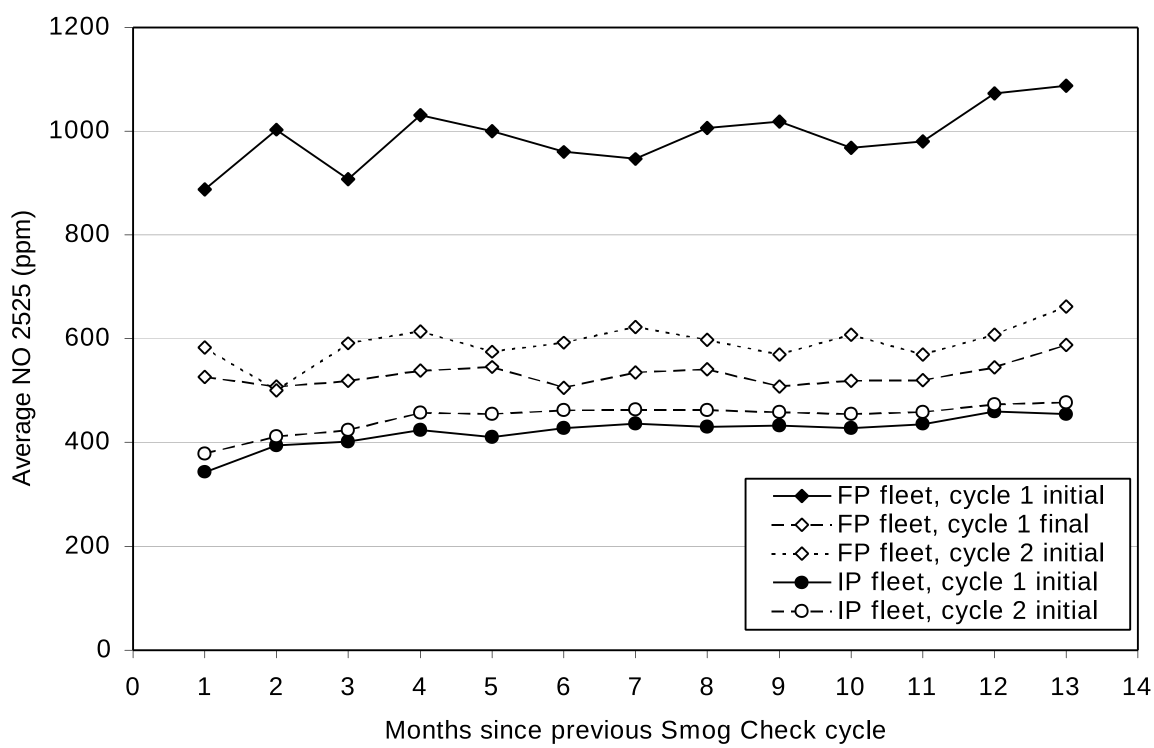
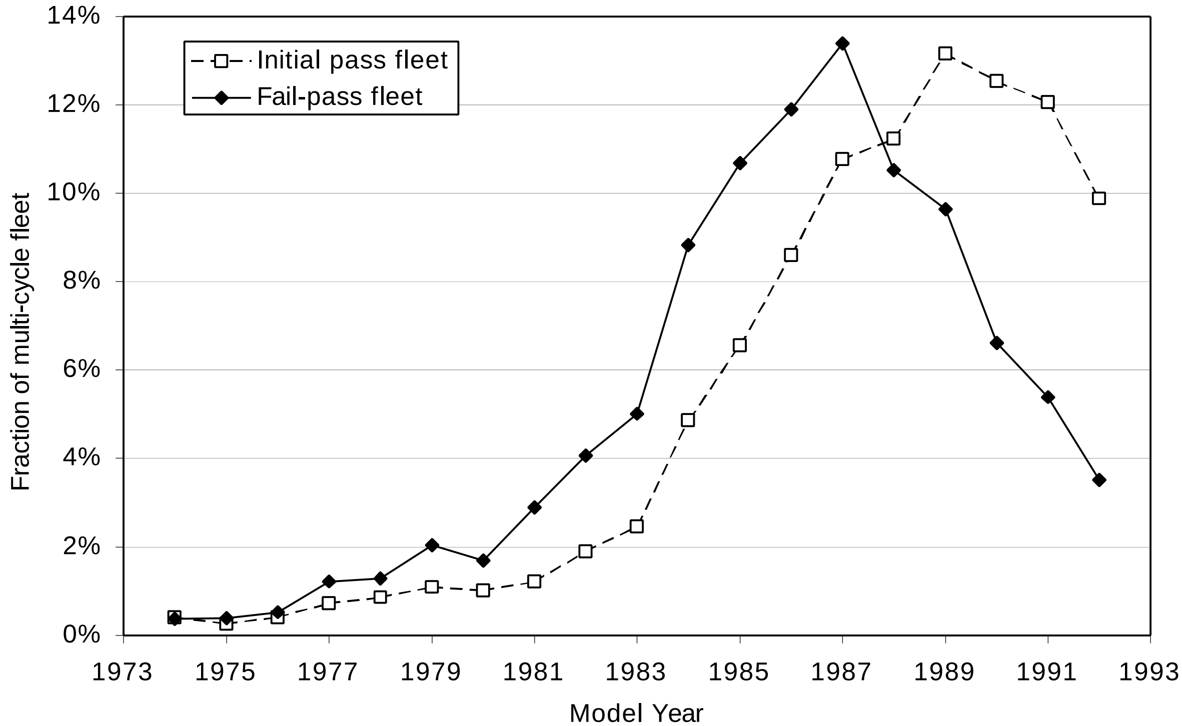


Figure C-12. Vehicle Distribution by Smog Check Result and Model Year



A potential problem with analyzing the multi-cycle vehicles is that their emissions may be different from vehicles that have never been sold, and that our findings based on them may not be applicable to the overall vehicle fleet. Figures C-13 through C-16 compare the failure rate, initial and final emissions, and percent emissions reduction of the multi-cycle fleet with the overall fleet, to determine if the emissions of the multi-cycle fleet are substantively different from the overall fleet. The figures exclude the no-final-pass vehicles from the overall fleet, since by definition there are no no-final-pass vehicles in the multi-cycle fleet (a passing test result is necessary to have a second Smog Check cycle). The figures are based on the first three months of testing under Phase 3 cut points, and the final test emissions for the multi-cycle fleet are the emissions reported for the final (passing) test of the initial Smog Check cycle.

Figures C-13 through C-16 indicate that the subset of fail-pass vehicles in the multi-cycle fleet has a lower initial failure rate, and lower average emissions, by model year than the subset of fail-pass vehicles in the overall fleet. Final emissions of the two fleets are the same. This suggests that the reduction in emissions is lower for the multi-cycle fleet (that we analyze) than the overall fleet, and that our estimate of program effectiveness based on the multi-cycle fleet may understate the actual effectiveness. We have no explanations for why the multi-cycle fleet has lower initial emissions than the overall fleet.

Figure C-13. Initial Fail Rate of Multi-Cycle and Overall Fleets

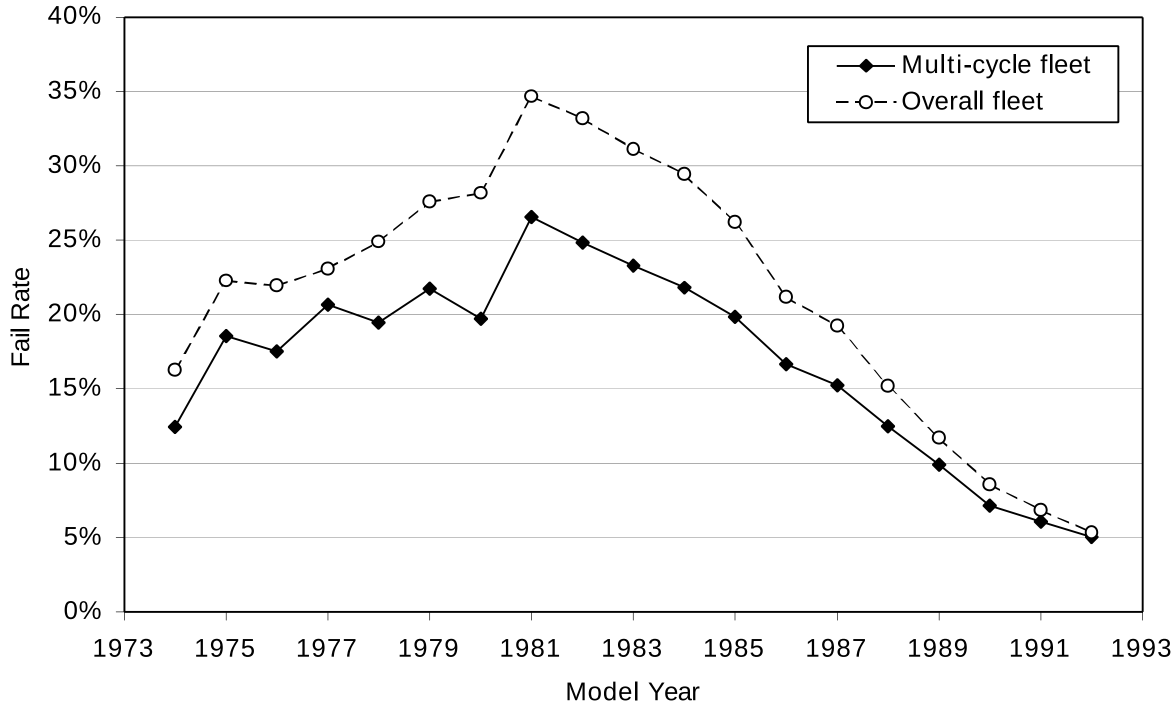


Figure C-14. Average HC 2525 Emissions of Fail-Pass Vehicles
by Fleet and Test

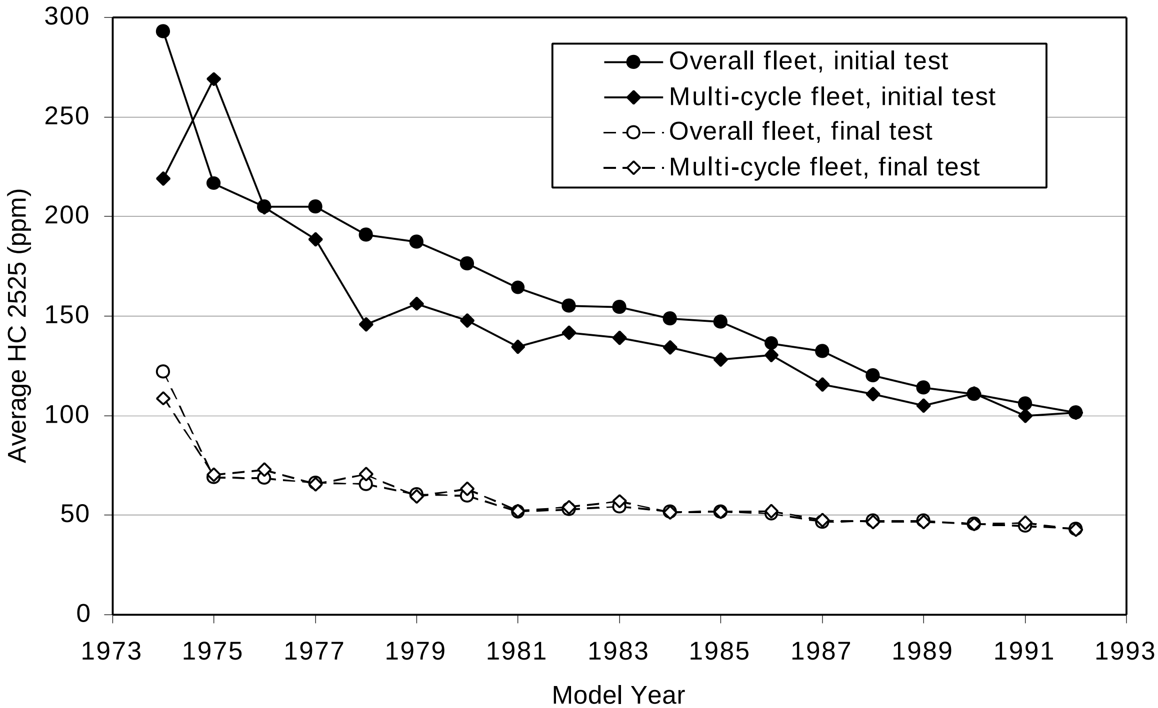


Figure C-15. Average CO 2525 Emissions of Fail-Pass Vehicles
by Fleet and Test

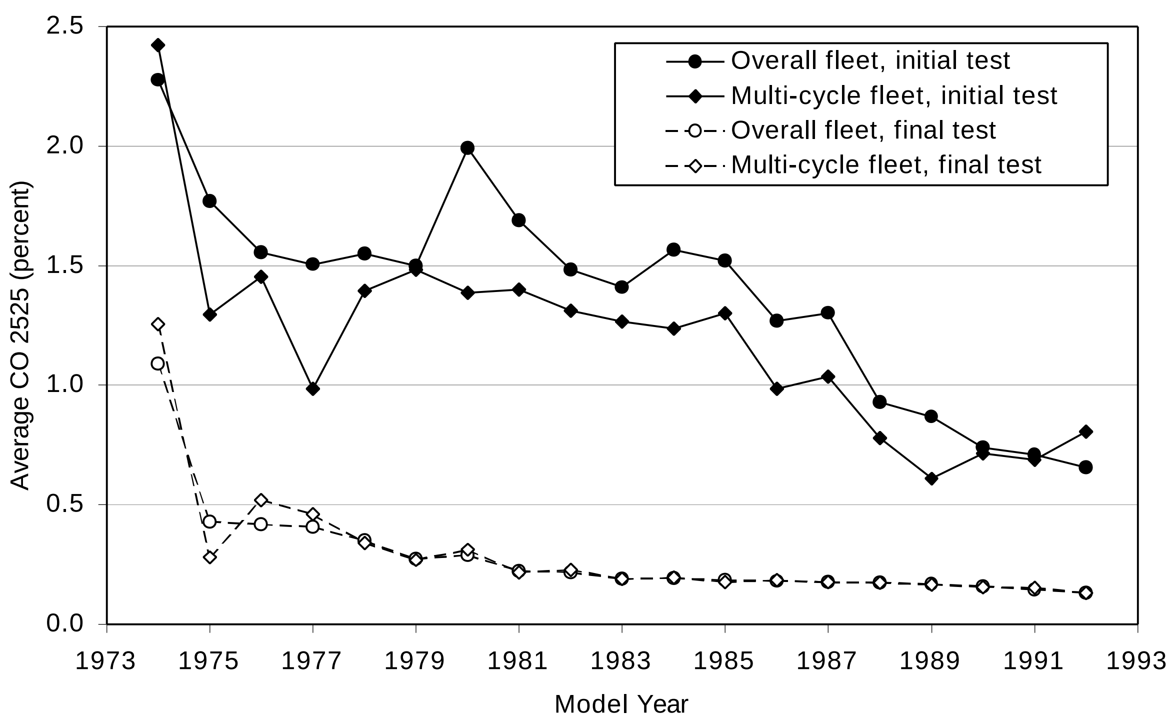
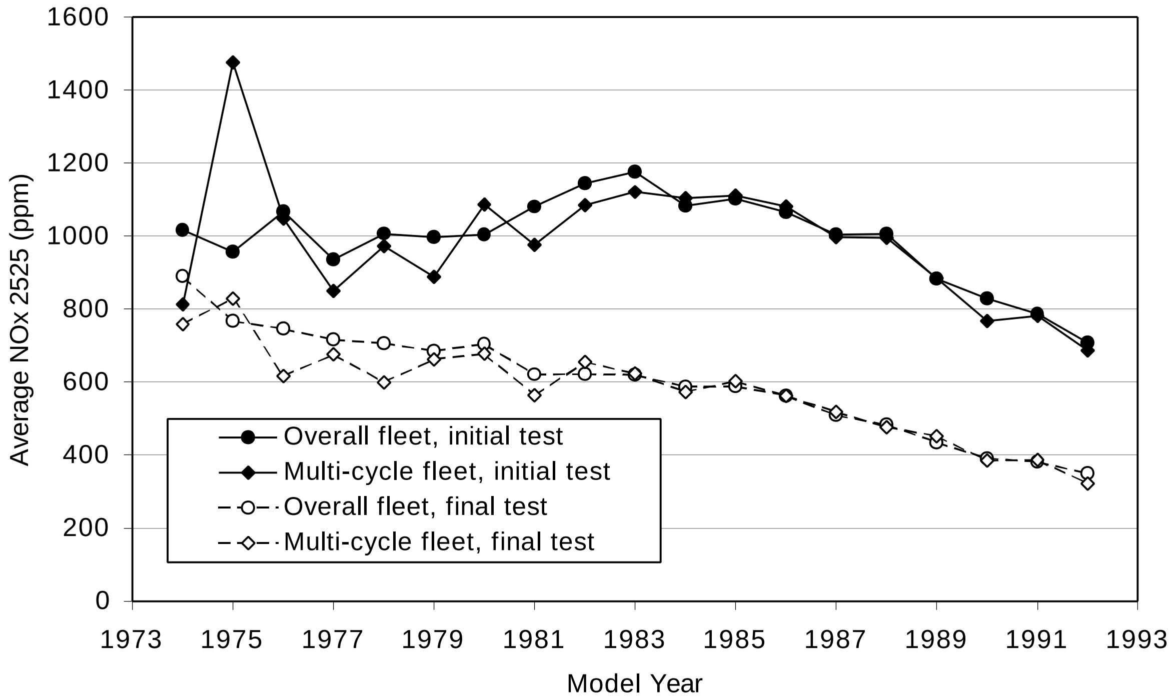


Figure C-16. Average NOx 2525 Emissions of Fail-Pass Vehicles
by Fleet and Test



Appendix D. Tons per day calculation

In this appendix we present additional details about our methodology and assumptions, and include tabular summaries of the data that we use to estimate incremental and overall one-cycle benefits of the Enhanced Smog Check program. The reader should consult Section 4.4 of the report for an overview of our methods. The tables, figures, and discussion presented in this section is intended as a supplement to Section 4.4, and not as an independent document.

We use a "bottom up" approach that multiplies average emission reductions per vehicle by the number of vehicles affected and the estimated activity per vehicle. Calculations are made by vehicle model year. For the incremental benefits analysis described in Section 4.4.2, we calculate average emissions using two methods that are further described below; one expresses pollutant emissions relative to fuel use (g/gal units), the other relates emissions to travel (g/mile units). Our estimates of overall one-cycle program benefits uses only gram-per-gallon emission factors. For the incremental analysis, we calculate an average emission difference (by model year) that is assumed to apply to the entire fleet of vehicles participating in Enhanced Smog Check. The one-cycle analysis examines separately three processes that contribute to overall emission reductions: pre-inspection maintenance and repair, post-failure repair, and removal of vehicles that do not pass Smog Check. Each of these processes affects a different sub-group of vehicles participating in Enhanced Smog Check.

Activity estimates are based on the average travel and fuel economy by vehicles of each model year. For the incremental analysis using g/mile emission factors, we need only to multiply by the estimated average miles traveled by model year. For the g/mile emission factors, we must estimate average fuel consumption per vehicle model year; this requires an estimate of average fuel economy. We use estimates of the average travel by model year provided to us by the Engineering and Research Section of the California Bureau of Automotive Repair (BAR).[6] The California Air Resources Board (CARB) provided estimates of the average in-use fuel economy by model year for the combined (car and truck) light and medium duty fleet in California, for calendar year 1999.[7] These values are shown in Table D.1 below.

---

6. Personal Communication: David Amlin, California Bureau of Automotive Repair, October 1999.
7. Personal Communication: Jeff Long, Mobile Source Control Division, California Air Resources Board, May 2000.

Table D.1. Estimated average travel and fuel economy by model year for the California combined light and medium duty fleet of vehicles in calendar year 1999. *(Travel estimates were provided by the California Bureau of Automotive Repair. Fuel economy estimates were provided by the California Air Resources Board.)*

Model Year	Avg. Fuel Economy (miles /gal)	Avg. Miles traveled in 1 year
1974	11.37	6027
1975	11.63	6207
1976	10.54	6448
1977	10.35	6380
1978	11.27	6512
1979	11.65	6781
1980	12.47	7066
1981	13.82	7327
1982	13.83	7959
1983	14.44	8154
1984	14.73	8471
1985	17.02	8722
1986	17.44	9061
1987	17.82	9441
1988	17.82	10032
1989	17.05	10550
1990	16.77	11103
1991	16.94	11733
1992	16.99	12375
1993	17.64	12950
1994	18.20	13577
1995	18.15	14162
1996	18.65	14441
1997	18.54	15169
1998	18.70	16296
1999	18.69	16194

D.1. Estimating Fleet FTP Emissions from ASM Measurements

Consultants from Eastern Research Group (ERG) have developed a series of statistical models designed to predict fleet average emissions that would be measured on the Federal Test Procedure (FTP) from actual ASM measurements of all vehicles in the fleet.[8] The models were developed using actual ASM and FTP emission measurements of vehicles recruited by the

8. Models for Estimating California Fleet FTP Emissions from ASM Measurements. Draft Report. Prepared for the California Bureau of Automotive Repair by T.H. DeFries, C.F. Palacios, S.D. Kishan (Eastern Research Group) and H.J. Williamson (Radian International). December 25, 1999.

California Air Resources Board for their in-use vehicle surveillance programs,[9] and for a study on the effectiveness of the ASM test as a tool to identify and repair of high-emitting vehicles. Emissions are expressed in units of gram of pollutant emitted per mile traveled. We urge the interested reader to obtain a copy of the report describing these models and their limitations; the report may be obtained by contacting the Engineering and Research Section of the California Bureau of Automotive Repair. The models use ASM test results to predict the FTP emissions that would be measured for each pollutant, from each vehicle. These modeled FTP emission factors are used to calculate average emission factors by model year for two groups of vehicles: those that have participated only in the Basic Smog Check Program, and those that have participated in the Enhanced Program. The resultant emission factors are referred to as predicted or modeled FTP emissions, since they are only predictions of the emission factors that would be measured by FTP testing. Some concerns about using this model are discussed later in this appendix.

D.2. Calculation of Fuel-Normalized (Gram/Gallon) Emission Factors from ASM Measurements

Fuel-normalized, gram-per-gallon emissions factors are calculated using the pollutant exhaust concentrations measured during the Smog Check ASM test and typical California reformulated gasoline properties. The calculated emission factors are referred to as direct ASM emissions, since they derive directly from the actual exhaust measurements. The calculation proceeds as follows:

D1 = molar concentration of fuel carbon in exhaust
    = $CO + CO_2 + (6 \times HC/10{,}000)$
D2 = moles of carbon per gallon of California reformulated gasoline
    = $0.85 \text{ (g C / g gasoline)} \times 743 \text{ (g gasoline / L)} \times 3.8 \text{ (L / gal)} \div 12 \text{ (g C / mole)}$

HC gram-per-gallon = $2 \times [(HC/10{,}000) / D1] \times D2 \times 86$
CO gram-per-gallon = $[CO / D1] \times D2 \times 28$
NOx gram-per-gallon = $[(NOx/10{,}000)/D1] \times D2 \times 46$

In these equations, HC, CO, NOx, and CO_2 are the exhaust concentration results from the ASM 2525 emissions test, and are in units of ppm (hexane-equivalents) HC, %CO, ppm NO, and %CO_2. The first bracketed terms in the gram-per-gallon equations represent the molar ratio of each pollutant to total carbon in the vehicle's exhaust (moles of pollutant/moles C). The last term is the molecular mass of each pollutant: 86 for hydrocarbons as hexane, 28 for CO, 46 for NOx as NO_2 (the conventional unit for reporting NOx emissions); these convert the emissions factors from moles to grams. The HC emissions factor is multiplied by an additional factor of 2 to account for the fact that the infrared technique used in the ASM test equipment measures only a portion of the many individual HC compounds in vehicle exhaust.[10]

9. The data for the ASM to FTP conversion were from CARB surveillance programs 13 and 14.
10. See Singer, B.C, R.A. Harley, D. Littlejohn, J. Ho, T. Vo. (1998). "Scaling of infrared HC remote sensor measurements for motor vehicle emission inventory calculations." *Environmental Science & Technology*, V32, 3241-3248.

D.3. Data used to estimate incremental benefits of Enhanced Smog Check

Average emissions by model year are shown for the Basic I/M and Enhanced I/M fleets in Tables D.2 and D.3, respectively. The first table shows FTP-modeled emissions, in g/mile units; the second is comprised of direct ASM emission factors, in g/gal units. Emission factors are calculated and/or derived from roadside ASM test results as described in Section 4.4 of the report. The total number of vehicles affected by Enhanced Smog Check is derived directly from VID records of all vehicles that participate in the program. Table D.4 shows that actual number of vehicles receiving ASM and two-speed idle Enhanced Smog Check tests during the 327 days of Phase 3 cut points. These numbers are adjusted to include the 5% of vehicles whose test records are not included in the regular VID because of data format irregularities (so called “bad” test records), and to a full two-year cycle of testing.

Table D.2. Average FTP-modeled emissions of vehicles participating in Basic and Enhanced Smog Check Programs, derived from roadside ASM test results. *(For the Enhanced I/M group, HC and CO emissions were calculated from all vehicles that had received an Enhanced Smog Check before roadside testing; NOx emissions were calculated only from vehicles that received their Enhanced test under Phase 3 cut points. Units: gram of pollutant emitted per mile traveled.)*

	# Vehicles Tested			Basic Smog Check Participants			Enhanced Smog Check Participants		
Model Year	Basic	All Enhanced	Phase 3 Enhanced	HC	CO	NOx	HC (All)	CO (All)	NOx (Phase 3)
1974	37	16	10	6.25	80.34	3.06	6.62	51.35	3.74
1975	26	20	12	8.21	73.00	2.67	5.08	48.79	3.35
1976	38	27	8	6.38	53.06	3.03	4.15	65.00	2.23
1977	74	61	33	7.26	65.11	3.04	3.54	47.65	2.43
1978	107	60	27	6.43	60.05	2.73	4.02	48.53	2.25
1979	104	86	45	4.58	56.68	2.53	4.24	44.18	2.41
1980	104	69	40	3.25	51.02	2.28	2.94	46.10	2.03
1981	154	83	48	3.82	52.79	2.10	2.75	41.39	2.22
1982	182	123	68	3.60	48.86	2.17	3.24	35.55	1.87
1983	248	160	93	3.15	41.62	2.26	2.33	28.52	1.86
1984	405	258	124	2.93	39.36	2.11	1.87	25.51	1.84
1985	539	371	193	2.18	30.85	1.94	1.91	23.69	1.63
1986	617	450	238	1.64	20.27	1.80	1.39	17.13	1.54
1987	487	409	243	1.51	19.78	1.63	1.49	17.04	1.42
1988	464	397	201	1.19	14.11	1.45	1.05	11.77	1.13
1989	538	414	226	0.88	10.56	1.16	0.93	10.38	1.19
1990	463	355	191	0.70	8.27	0.97	0.74	8.66	0.98
1991	455	361	193	0.58	7.10	0.83	0.54	6.24	0.76
1992	158	82	26	0.58	7.42	0.79	0.59	7.20	1.18
1993	173	66	30	0.38	5.08	0.61	0.38	4.77	0.52
1994	162	114	32	0.33	4.40	0.57	0.34	4.48	0.54
1995	193	47	31	0.29	3.87	0.49	0.29	3.75	0.42
1996	89	24	12	0.20	2.81	0.34	0.24	3.33	0.40
1997	11	4	-	0.16	1.99	0.28	0.13	1.96	-
1998	4	2	-	0.13	1.74	0.30	0.13	1.70	-

Table D.3. Average roadside ASM2525 emissions of vehicles participating in Basic and Enhanced Smog Check Programs, as measured during roadside testing. *(For the Enhanced I/M group, HC and CO emissions were calculated from all vehicles that had received an Enhanced Smog Check before roadside testing; NOx emissions were calculated only from vehicles that received their Enhanced test under Phase 3 cut points. Units: grams of pollutant emitted per gallon of fuel used.)*

	# Vehicles Tested			Basic Smog Check Participants			Enhanced Smog Check Participants		
Model Year	Basic	All Enhanced	Phase 3 Enhanced	HC	CO	NOx	HC (All)	CO (All)	NOx (Phase 3)
1974	37	16	10	40.90	667.5	70.47	68.39	350.6	107.54
1975	26	20	12	67.64	586.2	62.90	36.07	320.6	75.94
1976	38	27	8	55.04	349.7	63.82	27.40	610.3	45.36
1977	74	61	33	81.12	491.7	63.26	23.19	364.3	57.71
1978	107	60	27	68.80	557.0	61.44	29.85	359.7	52.78
1979	104	86	45	37.65	512.7	56.76	41.62	332.7	53.49
1980	104	69	40	26.73	604.7	66.29	23.09	496.6	58.24
1981	154	83	48	36.94	628.0	55.96	22.29	368.3	59.49
1982	182	123	68	38.91	626.4	60.43	34.56	391.3	47.91
1983	248	160	93	33.34	446.9	60.94	25.00	283.3	54.88
1984	405	258	124	31.54	470.6	54.86	17.57	240.2	47.97
1985	539	371	193	24.44	394.1	51.54	22.20	261.3	41.81
1986	617	450	238	18.21	214.6	48.75	14.98	171.1	37.57
1987	487	409	243	18.08	270.2	47.91	19.75	197.8	35.84
1988	464	397	201	15.49	153.0	39.97	12.20	109.1	26.03
1989	538	414	226	10.45	108.2	28.37	11.80	84.8	25.99
1990	463	355	191	8.03	63.5	22.16	8.88	71.1	21.41
1991	455	361	193	6.92	66.0	18.83	6.13	32.5	14.07
1992	158	82	26	7.33	67.9	19.90	7.32	61.6	26.07
1993	173	66	30	4.55	30.7	13.59	5.21	28.8	10.41
1994	162	114	32	4.28	20.8	13.13	4.50	31.7	9.88
1995	193	47	31	4.21	19.4	10.28	3.87	18.8	6.31
1996	89	24	12	3.00	11.4	6.32	3.41	12.3	6.81
1997	11	4	-	2.43	2.0	3.59	1.34	0.9	-
1998	4	2	-	1.73	0.9	6.44	2.57	3.6	-

Table D.4. Vehicles affected by Enhanced Smog Check.

Model Year	Actual vehicles tested by ASM during Phase 3	Actual vehicles tested by TSI[1] during Phase 3	Adjusted to 2 years of testing ($\times$ 1.12 $\times$ 2)	Including "bad" VID *records* ($\times$1.05)
1974	22079	5398	61548	64407
1975	16802	5134	49137	51419
1976	26985	7844	78017	81640
1977	40481	11336	116070	121461
1978	48812	13374	139297	145766
1979	58653	14105	162978	170547
1980	48101	9471	128961	134951
1981	58770	10862	155976	163220
1982	74896	11685	193941	202949
1983	98030	14932	253035	264787
1984	168561	15846	413072	432257
1985	214426	19456	523896	548228
1986	264739	23740	646193	676205
1987	296725	25394	721547	755059
1988	313301	28289	765162	800699
1989	351971	28625	852535	892131
1990	324571	30981	796436	833427
1991	317566	37755	795919	832885
1992	279164	38862	712378	745465
1993	314433	43534	801846	839088
1994	278141	36759	705376	738137
1995[2]	540914	61115	674272	705589
1996	128319	23422	339900	355686
1997	131938	24995	351530	367857
1998	97653	29664	285190	298436
1999	33248	7576	91446	95693
Totals	4549279	580154	10815657	11317990

[1] TSI = two speed idle test.   [2] All 1995 vehicles were tested in 1999.

D.4. Discussion of Incremental Benefits Analysis and Results

The results obtained using FTP-modeled and direct ASM emission factors may seem inconsistent with the understanding that the first approach should capture benefits during cold starts whereas the latter approach does not. One might expect that estimated benefits would be higher when "including" cold start emissions. However, this simplified characterization of the two methods does not completely describe differences between them.

The ASM-to-FTP model was designed to predict fleet-average emissions that would be measured on a full FTP test using ASM emissions test results for all vehicles in the fleet. It was developed using a sample of about 1370 vehicles participating in CARB's in-use vehicle surveillance programs (numbers 13 and 14), and the El Monte Pilot study on Enhanced I/M effectiveness.

Use of the model to predict FTP emissions of the Enhanced Smog Check fleet assumes that the ASM to FTP relationship of the test sample (stratified by technology and several other factors) reflects the ASM to FTP relationship of the overall Smog Check fleet. There are a number of reasons why this might not be so. First, the surveillance program fleets are widely believed to include a much lower percentage of high-emitters than the overall California fleet and average fleet emissions are determined by high emitters. Second, FTP emissions of properly functioning, and many marginally malfunctioning vehicles are largely determined by emissions during the cold start portion of the FTP; this is because emissions are lowered by emission control equipment during all other parts of the test. The highest emitters that drive fleet average emission do not have properly functioning emission control equipment; their emissions during "cold start" should therefore not be significantly higher than emissions during the rest of the FTP (i.e. very low start emissions). Since the ASM to FTP model predicts FTP (including cold start) emissions from a test that is administered while vehicles are fully warmed up (the ASM), the model inherently includes assumptions about the relative importance of warmed running and additional cold start emissions to total FTP cycle emissions. But there is clear reason for concern that the relative importance of cold starts among the sample of vehicles used to develop the models differs from the relative importance of cold starts for the overall in-use fleet, which likely includes more high emitters. Thus, the ASM to FTP model may not be a valid tool for predicting FTP emissions from ASM measurements of the total in-use fleet.

Use of the ASM to FTP model to predict Smog Check induced emissions *reductions* is even more tenuous. The model over-predicted by 5% to 30% the measured FTP HC reductions, and over-predicted between 20% low and 37% high the FTP NOx reductions, by model year group, from the vehicle fleet used to develop the model. The ability of the model to achieve even these same results for the overall in-use fleet depends on many factors, starting with the model's accuracy in predicting overall in-use fleet emissions (as described above). To the extent that I/M repairs substantially change the fraction of high emitters and/or the fraction of total emissions associated with cold starts, the model may also not accurately capture actual FTP emissions reductions. This is because the inherent assumptions about fraction of total emissions associated with cold starts are applied to both the before and after I/M fleets. The extent to which repairs reduce emissions during warmed running vs. during cold start may also impact the ability of the model to accurately capture benefits.

The second method used to estimate overall benefits, i.e. the direct ASM measurements expressed in g/gal units, is also subject to many uncertainties and potential biases. This method uses emissions measured under a single, moderate engine load as a surrogate for emissions under all engine loads. Previous research[11] has shown that for HC and CO, fuel-normalized (e.g. g/gal) emissions measured from the on-road fleet at moderate load could be used to predict with reasonable accuracy emissions over a much more broad range of loads. Combining this with the fact that most fuel is burned during positive loads, it was shown that measurements of fuel-normalized emissions at moderate load could be used to estimate fleet average emissions over a distribution of loads reflective of overall California driving in the early 1990s. However, these results were based on measurements made from vehicles under a moderate load amidst transient driving, whereas the ASM test is based on a static moderate load. Also, the previous research did not address NOx emissions.

On the first concern, we may consider the data presented later in this appendix that compares average ASM emissions by model year, as measured in the Smog Check program to average emissions by model year measured by on-road remote sensing, at loads that are similar to the ASM test. Understanding that there are several potential reasons for the difference, we simply note here that on-road emissions of HC and CO are higher, and on-road emission of NOx are similar to those measured during the ASM. Fleet average NOx emissions show a first order dependence on load over a range of positive loads, leveling off only at very high loads where fuel enrichment may occur (this raised HC and CO significantly but lowers NOx). Since the load of the ASM is relatively moderate, we expect that fuel normalized NOx emissions over the full range of positive loads would be higher than those measured at the moderate load of the ASM. Thus, we expect that our method of using direct ASM emissions normalized to fuel use likely understates average emissions over the full in-use distribution of warmed-up driving.

The method also makes two additional assumptions. First, we assume that emission reductions measured on the ASM test apply to vehicle usage at other positive loads (again, recall that we are using fuel-normalized emission factors and most fuel is used during positive load vehicle operation). Next, we assume that the absolute ASM emission reduction induced by the I/M program (in g/gal units) applies over all vehicle activity, including cold start. Note that this does not assume any additional benefits during cold start, just the same emissions reductions for fuel consumed during cold start as during warmed running operation.

In summary, each of the two methods described above includes several assumptions that may lead to differences in the way that emissions reductions measured on the ASM test are used to predict overall emissions reductions from the in-use fleet.

D.5. Calculation of benefits from pre-inspection maintenance and repairs

We use roadside ASM test data to estimate emissions of the Enhanced Smog Check fleet prior to any pre-inspection maintenance and repairs. We select only those vehicles that are likely or known to participate in the Enhanced Smog Check program, i.e. vehicles with a confirmed Basic I/M test prior to roadside or a subsequent Enhanced Smog Check test. To reduce any bias

11. Singer, B.C. "A Fuel-Based Approach to Estimating Motor Vehicle Exhaust Emissions". Ph.D. Dissertation, U.C. Berkeley, 1998. Chapter 5.

introduced by Basic I/M effects, we include only those vehicles that received their Basic I/M test more than one year before being pulled over at the roadside. This fleet of vehicles is slightly different than the fleet we use to estimate incremental program benefits, described above. Table D.5 shows the average emissions by model year for these vehicles.

Average emissions following pre-inspection maintenance and repairs are those that are measured at the first official test or pre-test in the Enhanced Smog Check program, and reported in the VID database; these are calculated directly from the VID. We assume that the benefit of pre-inspection maintenance and repairs is experienced mainly by those vehicles that pass their first official Smog Check; benefits for vehicles that fail their initial Smog Check are discussed in the next sub-section. Table D.5 includes the initial emissions of the entire fleet, as measured during Phase 3 cut points, and the total number of initial pass vehicles tested by ASM and two-speed idle. These raw vehicle numbers must be converted to a full year of testing and adjusted to account for the vehicles with bad data formats that are not included in the VID.

Table D.5. Data used to calculate pre-inspection benefits.

	Initial Pass vehicles in Phase 3 (327 days)		Full year	Average emissions before pre-inspect (from roadside data)			Average emissions of total fleet at initial official Smog Check (from VID)		
Model Year	ASM	Two-speed idle	Incl "bad" records	HC	CO	NOx	HC	CO	NOx
1974	17186	3567	24323	42.83	584.8	72.16	38.51	441	58.82
1975	12149	3202	17992	74.55	561.4	64.72	29.96	309.5	55.71
1976	19615	4334	28069	61	371	53.43	29.24	282.7	59.24
1977	28782	6430	41269	88.7	477.3	57.55	28.48	285.5	56.47
1978	33760	7476	48329	68.65	572.1	60.42	28.13	278.3	55.81
1979	39614	4753	51999	41.88	562.8	51.16	26.95	262.2	53.75
1980	32162	3631	41950	27.14	639.6	68.24	25.36	323.5	54.36
1981	36231	4083	47249	39.72	631.6	57.78	25.12	308.5	53.43
1982	46488	5085	60445	36.41	641.5	61.09	24.34	276.4	54.58
1983	62976	7087	82115	31.8	482.8	61.44	22.99	248.7	53.4
1984	111766	11973	145024	33.02	480.2	54.79	21.76	256.6	48.68
1985	149441	15014	192744	25.85	383.3	52.63	20.1	221	47.06
1986	200061	18908	256636	18.32	203.7	47.33	17.13	162.9	42.42
1987	228323	20351	291450	17.57	262.2	46.05	15.77	156.3	38.03
1988	256888	23417	328523	16.64	160.3	39.29	13.61	105.2	33.09
1989	302318	24596	383149	10.99	115.6	27.5	11.98	86.54	26.37
1990	290060	27674	372390	7.932	64.81	21.61	10.54	66.85	22.44
1991	290091	34654	380607	7.305	69.22	18.56	9.561	57.41	19.74
1992	260463	36401	347930	7.521	72.44	18.68	8.568	48.08	16.45
1993	298522	41502	398514	4.623	29.81	11.48	6.837	37.97	12.27
1994	269426	35516	357398	4.547	21.31	10.29	5.532	26.83	10.1
1995	529588	59452	690366	4.356	20.58	8.46	4.32	18.33	8.753

Note in Table D.5 that for newer vehicle model years VID emissions tend to be slightly higher than emissions measured during roadside testing. We suspect that this is evidence of a preconditioning effect on the vehicles tested in the VID. That is, the emissions of some vehicles that are fast-passed during VID testing would be lower if they were tested over the full ASM test cycle. All vehicles given roadside ASM tests were given the full ASM test cycle; clean vehicles were not allowed to fast-pass the test. Since the majority of vehicles fast-pass VID testing, this effect would tend to overstate fleet emissions measured in the VID as compared with fleet emissions measured during roadside testing.

D.6. Calculation of benefits from post-failure repairs

We estimate the emissions reduction from repair using our analysis of vehicles that fail, then pass during their initial Smog Check cycle, then start another Smog Check cycle within 12 months; this analysis is discussed in Sections 4.1 and 4.2, and Appendix B. The base Year 1 emissions reduction from repair of fail-pass vehicles is calculated by subtracting the average emissions measured during the initial test of the second cycle from average gram-per-gallon emissions measured during the initial (failing) test of the first cycle, these emissions factors are shown in Table D.6. The difference between these emissions factors represents the minimum effect of the Smog Check program on the average gram-per-gallon emissions of fail-pass vehicles by model year, during the first year of the program. In the absence of the Smog Check program, it is likely that the emissions of fail-pass vehicles would have increased on average over this time period. The program should receive credit for preventing this increase. As a conservative (high) estimate, we assume that the fail-pass vehicles would deteriorate over one year to the average emissions levels of vehicles that fail an initial test, but never receive a passing Smog Check (no-final-pass vehicles). Our best estimate assumes that fail-pass vehicles deteriorate to the no-final-pass levels over a two-year period. Average gram-per-gallon emissions of the no-final-pass vehicles, as measured during the initial (failing) Smog Check, are shown in Table D.7. The avoided deterioration is half the difference between the initial gram-per-gallon emissions by model year of the no-final-pass and fail-pass vehicles, each on the initial test of their first cycle. Assumptions about emissions levels of fail-pass vehicles in Year 2 are discussed below.

Table D.6. Average gram-per-gallon emissions of vehicles that fail, then pass in an initial Smog Check cycle and are re-tested in a second Smog Check cycle within 12 months (FAIL-PASS). *Results from ASM 2525 emissions test.*

	Initial (failing) test of first cycle			Initial test of second cycle		
Model Year	HC	CO	NOx	HC	CO	NOx
1974	49	845	62	45	511	65
1975	51	532	89	26	415	54
1976	62	448	81	40	219	60
1977	43	433	61	29	262	47
1978	42	556	69	24	257	43
1979	43	559	66	27	247	47
1980	35	540	76	19	232	50
1981	33	506	69	19	202	43
1982	34	467	75	19	194	47
1983	32	459	76	18	161	45
1984	32	487	71	18	192	43
1985	31	472	73	19	193	42
1986	30	371	71	17	144	41
1987	28	393	65	16	144	38
1988	25	273	63	15	123	34
1989	24	237	57	15	113	31
1990	25	237	54	15	100	30
1991	23	228	48	15	75	27
1992	23	246	44	14	71	26
1993	20	167	36	11	56	19
1994	16	148	33	9	62	17
1995	14	159	29	7	39	14
1996	13	206	12	6	41	13
1997	9	175	11	4	25	5
1998	7	61	11	2	12	4
1999	6	5	3	2	3	9
Weighted averages	29.4	376.4	63.8	17.4	154.6	37.9

Table D.7. Average gram-per-gallon emissions of vehicles that fail an initial Smog Check test and do not receive a passing test (NO-FINAL-PASS). *Results from ASM 2525 emissions test.*

	Initial (failing) test of first cycle		
Model Year	HC	CO	NOx
1974	156	1098	56
1975	109	951	56
1976	108	896	58
1977	99	908	53
1978	83	936	57
1979	91	962	56
1980	76	1172	55
1981	67	1015	61
1982	62	895	69
1983	58	898	68
1984	56	986	63
1985	55	946	63
1986	52	822	67
1987	51	861	62
1988	48	651	64
1989	47	571	66
1990	43	432	70
1991	38	383	67
1992	33	328	61
1993	35	316	51
1994	30	312	50
1995	26	273	38
1996	19	226	20
1997	15	405	28
1998	13	326	10
1999	15	447	1
Weighted averages	54.8	763.0	62.7

Table D.8. Average gram-per-gallon emissions of vehicles that pass an initial Smog Check cycle and are re-tested in a second Smog Check cycle within 12 months (INITIAL PASS). *Results from ASM 2525 emissions test.*

	Initial (passing) test of first cycle			Initial test of second cycle		
Model Year	HC	CO	NOx	HC	CO	NOx
1974	28	332	58	31	429	55
1975	18	165	57	30	255	56
1976	18	135	59	22	238	55
1977	18	149	57	20	228	52
1978	17	133	52	23	192	50
1979	15	92	50	20	178	49
1980	15	99	48	19	200	48
1981	15	87	45	23	194	48
1982	14	93	44	19	175	45
1983	14	82	43	18	145	46
1984	13	79	40	18	166	42
1985	13	75	38	17	143	40
1986	12	69	36	14	113	37
1987	11	65	32	14	108	33
1988	10	59	29	12	88	30
1989	10	55	23	11	76	24
1990	9	49	20	10	61	21
1991	8	45	19	9	53	19
1992	8	39	16	9	46	16
1993	7	33	12	7	40	12
1994	5	25	10	6	30	10
1995	4	17	9	5	21	8
1996	3	13	6	3	13	5
1997	2	10	4	3	12	4
1998	2	7	3	2	6	3
1999	1	4	3	1	4	3
Weighted averages	11.8	71.5	33.5	14.7	121.1	34.4

In order to estimate the benefit of the program over a full two-year cycle, we need to make assumptions about the deterioration of fail-pass vehicles in the second year, with and without the Smog Check program. Because this estimate is so uncertain, we provide estimated upper and lower bounds on program benefits, i.e. minimum and maximum benefits that are likely attributable to the program, in addition to our best estimate. The assumptions we use for our low and high benefit estimates for the fail-pass fleet are described below. These are shown schematically below.

Our lower bound benefit estimate of repair benefits makes two assumptions about the fail-pass fleet:

1. In the absence of the Smog Check program, their emissions would not have increased over the two-year period.
2. Their emissions after repair will increase over the second year of the program back to the levels measured during their initial (failing) Smog Check. In other words, the benefit from repair in the second year is half of the benefit from repair in the first year.

Our upper-bound estimate of program benefits from repair assumes the following about the fail-pass fleet:

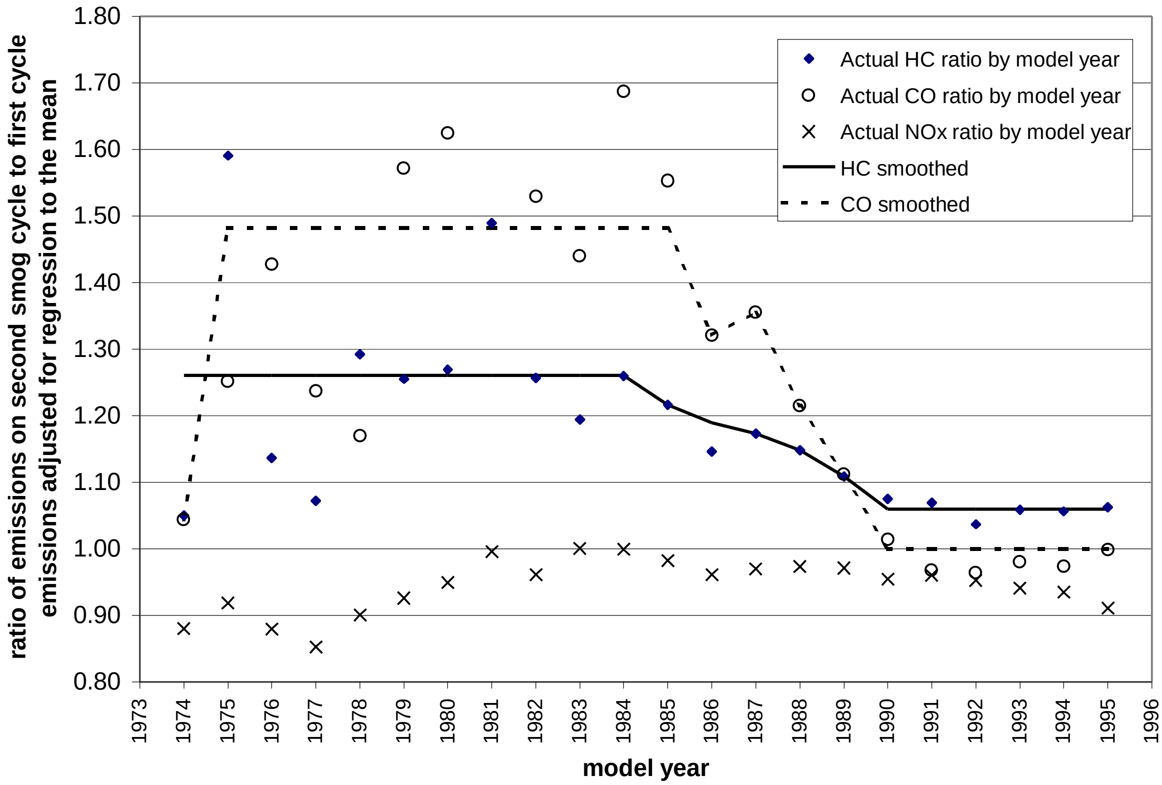
1. In the absence of the Smog Check program, the fail-pass fleet emissions would have increased to the observed level of the no-final-pass fleet emissions, by the end of the first year, and would have stayed at that level throughout the second year.
2. The after-repair emissions of the fail-pass fleet will remain for the second year at the same level as they were in the first year after Smog Check.

Our best estimate assumes the following about the fail-pass fleet:

1. Emissions would deteriorate to no-final-pass levels over a two-year period if Smog Check were ended.
2. In the second year following Smog Check, emissions would increase at the same rate as that observed in the initial pass fleet in the first year of the program. This deterioration rate was determined by model year, by comparing the average emissions of initially passing vehicles during their first cycle (adjusted for regression to the mean, see below) to emissions measured 1-12 months later on their next Smog Check cycle. Average emissions factors by model year for initially passing vehicles are provided in Table D.8 and regression to the mean factors for initial pass vehicles are shown in Table D.7. The ratio of second initial emissions to regression to the mean adjusted-first cycle initial emissions, by model year, is shown in Figure D.1 below. Since there was significant variation in the actual deterioration rate from one model year to the next, we used the smoothed deterioration "curve" shown in the figure. Since NOx emissions were actually lower on the second cycle compared to the adjusted first cycle emissions, we assume no deterioration for NOx.

The total number of fail-pass vehicles affected by the program is shown in Table D.9.

Figure D.1. Deterioration of Initial Pass vehicles averaged over one year: ratio of emissions during second Smog Check cycle to first cycle emissions adjusted for regression to the mean.



D.7. Estimate of benefits from replacement of vehicles that never pass Smog Check

We estimate the emissions reduction for replacement by assuming that each no-final-pass vehicle is replaced with an initially passing vehicle. Our best and upper bound estimates both assume replacement with a vehicle that is five years newer. Our lower estimate assumes replacement with a vehicle of the same age. We use the average emissions measured during the second Smog Check cycle, for vehicles that initially passed their first cycle; this accounts for deterioration of initially passing vehicles over the first year following Smog Check. These emissions are shown in Table D.8. No deterioration is assumed for the no-final-pass fleet in the absence of the Smog Check program. Average emissions of these vehicles are very high at the start, and we assume that over time, some of these vehicles would receive necessary mechanical repairs (that would in some cases lower emissions) or be retired for reasons unrelated to Smog Check. These processes are assumed to balance the emissions deterioration that would occur among other no-final-pass vehicles. Assumptions regarding Year 2 are discussed below.

For replacement of vehicles that do not pass Smog Check, our best estimate assumes a second year benefit that is half of the first year benefit. This accounts for the continued deterioration of the replacement vehicles (about which we know little), and the reasonable assumption that at least some of the no-final-pass vehicles would have been retired during the second year, for reasons unrelated to Smog Check.

A lower-bound benefit is estimated by assuming that all no-final-pass vehicles would have been retired within one year of their initial test for reasons unrelated to Smog Check, i.e. no second year benefit for the replacement of no-final-pass vehicles. The high estimate for the second year is twice the estimated first year benefit.

We estimate the number of vehicle replacements induced by Smog Check from the number of vehicles that fail an initial Smog Check but never receive a passing test. This number is discounted by the observed rate that such vehicles are still seen on the road more than one year after their initial failure, i.e. one-third of the no-final-pass vehicles. This means that two-thirds of the vehicles are assumed to be removed from the road. The number of vehicles affected is shown in Table D.10.

Table D.9. Number of Fail-Pass vehicles used to estimate emissions reduction benefits from vehicle repair.

Model Year	Actual vehicles tested in 327 days of Phase 3	Adjustment factor to include two-speed idle tests	Adjusted to one full year plus “bad” records
1974	3253	1.24	4745
1975	3390	1.31	5187
1976	5364	1.29	8113
1977	8549	1.28	12825
1978	11027	1.27	16464
1979	14311	1.24	20807
1980	11717	1.20	16437
1981	17010	1.18	23621
1982	21799	1.16	29535
1983	27176	1.15	36703
1984	44429	1.09	56967
1985	51458	1.09	65782
1986	51507	1.09	65781
1987	55463	1.09	70566
1988	45324	1.09	57917
1989	40294	1.08	51066
1990	28219	1.10	36230
1991	22537	1.12	29554
1992	15435	1.14	20608
1993	13129	1.14	17519
1994	6755	1.13	8963
1995	8856	1.11	11552
1996	1094	1.18	1516
1997	970	1.19	1352
1998	414	1.30	632
1999	84	1.23	122

Table D.10. Number of No-Final-Pass vehicles in VID. *Replacement of two-thirds of these vehicles is credited to the Smog Check Program.*

Model Year	Actual vehicles tested in 327 days of Phase 3	Adjustment factor to include two-speed idle tests	Adjusted to one full year plus "bad" records
1974	683	1.24	996
1975	746	1.31	1142
1976	1140	1.29	1724
1977	1868	1.28	2802
1978	2538	1.27	3790
1979	3250	1.24	4725
1980	3034	1.20	4256
1981	4310	1.18	5986
1982	5008	1.16	6786
1983	5653	1.15	7635
1984	8762	1.09	11234
1985	8796	1.09	11244
1986	7386	1.09	9432
1987	7139	1.09	9083
1988	5098	1.09	6515
1989	3527	1.08	4470
1990	2081	1.10	2672
1991	1425	1.12	1870
1992	835	1.14	1115
1993	644	1.14	860
1994	346	1.13	459
1995	405	1.11	529
1996	71	1.18	98
1997	40	1.19	56
1998	16	1.30	25
1999	8	1.23	11

The uncertainty in vehicle counts is very low, probably less than 5%. We estimate that the annual mileage accumulation values are accurate to within +/- 10% or better, and the fuel economy values to within +/- 20% or better. If higher emitting vehicles as a group have mileage accumulation rates and fuel economy values that differ markedly from the average values by model year this will introduce some bias into the benefits calculations.

The conversion from grams to tons includes the following relationships: 1 kg = 1000 g = 2.2 lb. and 1 ton = 2000 lb.

Table D.11 presents our best estimate of the one-cycle benefits from the Enhanced Smog Check program, in tons per day of pollutant emissions prevented. The table shows the distribution of emissions benefits by model year. The table also shows the sensitivity of our best estimate to the assumptions we use, expressed as lower and upper bounds on that estimate.

Table D.11. Estimated total tons per day of pollutant emissions prevented by the Enhanced Smog Check program, including pre-inspection maintenance, post-failure repair, and replacement. Best estimate and lower and upper bounds (see text for details).

Model	Best estimate			Lower bound			Upper bound		
Year	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
1974	3.7	31.2	0.3	2.0	19.0	0.2	5.2	40.4	0.4
1975	3.7	28.1	0.6	2.1	17.3	0.6	5.0	39.6	0.6
1976	4.2	37.1	0.6	2.4	20.7	0.6	5.7	50.4	0.6
1977	5.0	43.2	0.8	2.5	22.4	0.6	6.9	60.8	0.8
1978	5.2	52.6	1.3	2.7	28.7	1.1	7.0	71.0	1.3
1979	6.0	62.7	1.3	2.9	33.4	1.1	8.2	84.3	1.3
1980	5.1	62.4	1.2	2.7	30.9	1.2	6.8	84.5	1.1
1981	5.1	107.1	3.2	2.6	59.8	2.4	7.0	143.2	3.7
1982	5.7	114.3	4.2	3.0	63.8	3.1	7.6	153.1	4.7
1983	6.1	130.4	5.0	3.1	70.8	3.7	8.2	172.4	5.4
1984	7.9	176.2	6.6	4.0	90.6	5.1	10.7	235.8	7.0
1985	7.7	170.8	7.1	3.8	88.3	5.6	10.4	229.4	7.4
1986	5.4	134.6	8.7	2.2	62.4	6.4	7.1	177.9	9.7
1987	5.7	149.5	8.8	2.3	69.1	6.4	7.5	197.2	9.8
1988	4.6	105.6	8.7	1.7	47.6	6.1	6.1	140.6	9.9
1989	4.1	93.4	8.5	1.4	42.3	5.5	5.6	123.5	10.0
1990	3.1	70.8	7.3	1.2	38.1	4.4	3.9	90.1	8.9
1991	0.4	35.9	3.5	-0.3	17.5	1.8	0.5	43.1	4.1
1992	-0.2	26.3	2.2	-0.4	14.9	1.1	-0.5	30.4	2.6
1993	-0.3	20.9	1.7	-0.6	10.0	0.9	-0.5	26.0	1.9
1994	-1.0	13.1	0.8	-0.9	6.5	0.4	-1.4	16.8	1.0
1995	-0.9	16.0	0.9	-0.8	8.6	0.5	-1.2	19.6	1.0
1996	0.1	1.3	0.0	0.0	0.8	0.0	0.1	1.3	0.0
1997	0.1	1.8	0.1	0.0	0.7	0.0	0.1	2.2	0.1
1998	0.0	0.6	0.0	0.0	0.1	0.0	0.0	0.9	0.0
1999	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0
Total tons per day	86.4	1686.0	83.4	39.5	864.1	58.8	116.1	2235.2	93.3

D.8. Regression to the Mean

Although we account for the single test bias in the emissions of fail-pass vehicles on their passing test (by using the emissions from their next test, rather than from their passing test), our best estimate does not include an adjustment to the initial (failing) emissions of fail-pass vehicles. If tested again, the average emissions of these vehicles likely will be lower; to the extent that this is so, a smaller emissions reduction benefit should be credited to the Smog Check program. We refer the reader to Appendix A for a general discussion of the regression to the mean phenomenon.

We use the following procedure to estimate how much lower the emissions of the fail-pass fleet would be if it were re-tested *without* repair. First, we assume that if the entire fleet of initial pass *and* fail-pass vehicles were re-tested immediately, without any maintenance or repair, overall average emissions of the *combined* fleet would be the same as measured on the initial Smog Check test. Next, we estimate the emissions *of initial pass vehicles that would be measured* if an immediate re-test were given to each vehicle (see discussion below and Figures D.2 through D.4). Finally, we calculate the second test emissions of fail-pass vehicles that would be required to preserve the overall average emissions of the combined fleet from the initial test to the hypothesized immediate re-test. A summary of this calculation is shown in Table D.12 below. The table indicates that the emissions of the fail-pass fleet *might* be approximately 11% lower for HC, 24% lower for CO, and 20% lower for NOx if it were immediately re-tested.

Table D.12. Multi-cycle data used to estimate the emissions that *would be observed* if initially failing vehicles (FAIL-PASS) were immediately re-tested without repair.

	HC (ppm hexane)	CO (%)	NOx (ppm)
Initial test emissions of combined fleet	52.8	0.268	493.6
Initial test emissions of Initial Pass vehicles	42.4	0.156	421
Initial Pass vehicle fraction	0.873	0.873	0.873
Initial test emissions of Fail-Pass vehicles	124	1.036	990
Fail-Pass vehicle fraction	0.127	0.127	0.127
Regression to the mean effect on IP vehicles (see Figs D.2 to D.4)	1.046	1.236	1.067
Estimated re-test emissions of IP vehicles	44.4	0.193	450
Estimated re-test emissions of FP vehicles	111	0.783	796
Apparent FP emissions reduction due to regression to the mean	-11%	-24%	-20%

Figures D.2 through D.4 show the average emissions of the initial pass vehicles in the multi-cycle fleet by the number of months since their initial Enhanced Smog Check test. We draw a regression line through the first six months of data for HC and CO to determine what the emissions of the initial pass vehicles would be if they were re-tested immediately after their initial passing test. The y-intercepts indicate that HC emissions would be 5% higher and CO

Figure D.2. Ratio of HC emissions from multi-cycle fleet initial pass vehicles to their previous test emissions, by time since initial Smog Check cycle.

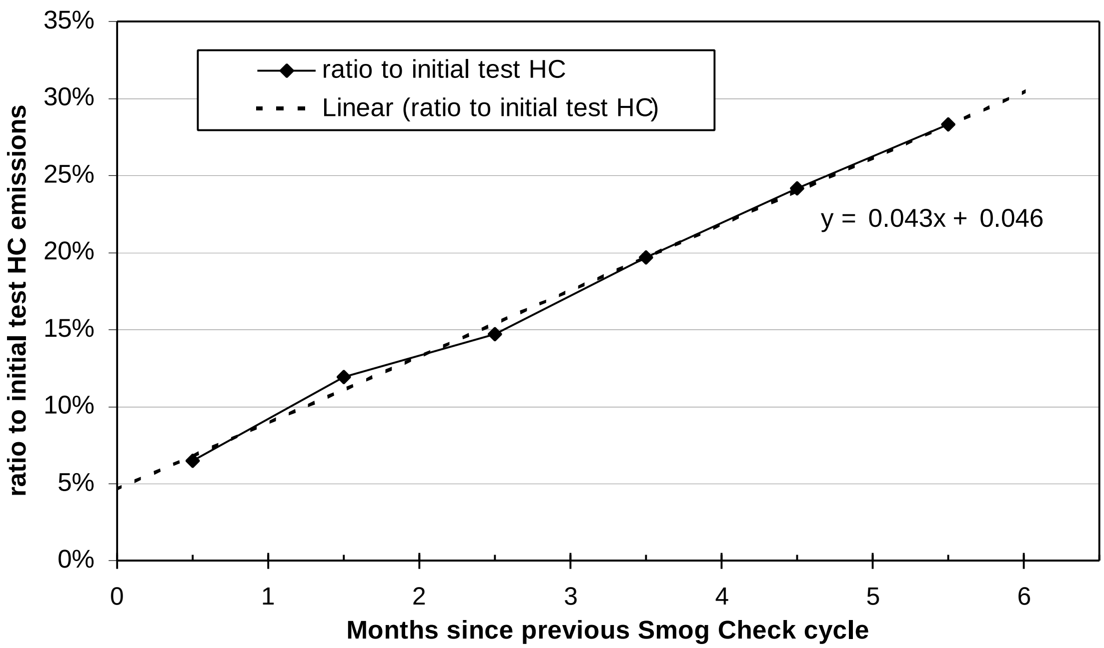


Figure D.3. Ratio of CO emissions from multi-cycle fleet initial pass vehicles to their previous test emissions, by time since initial Smog Check cycle.

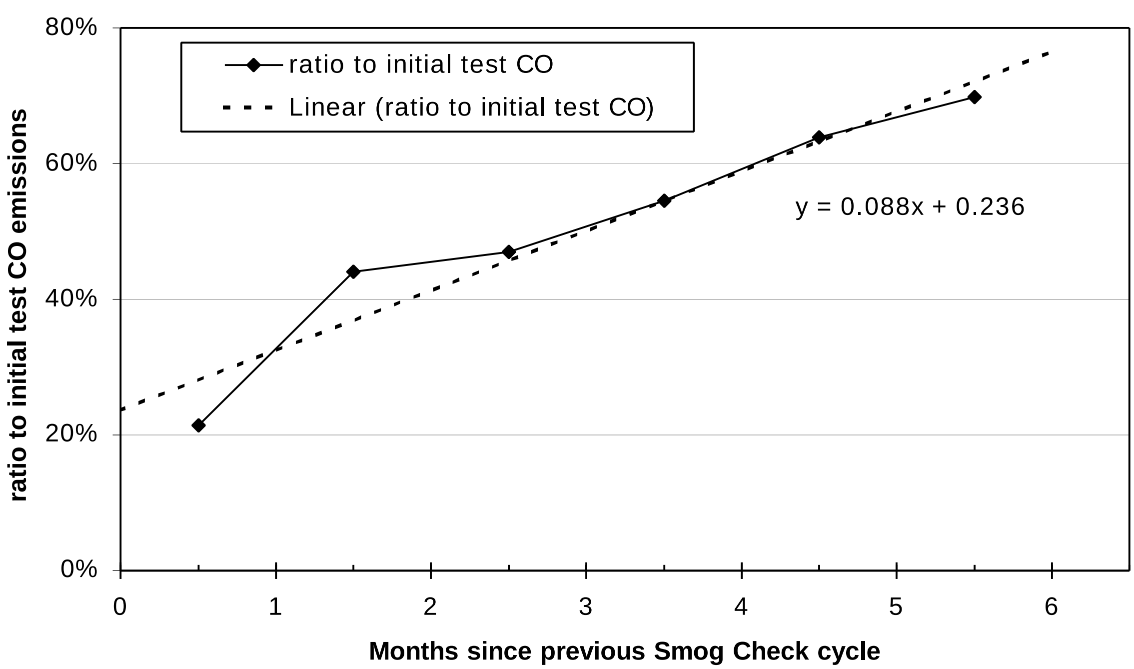
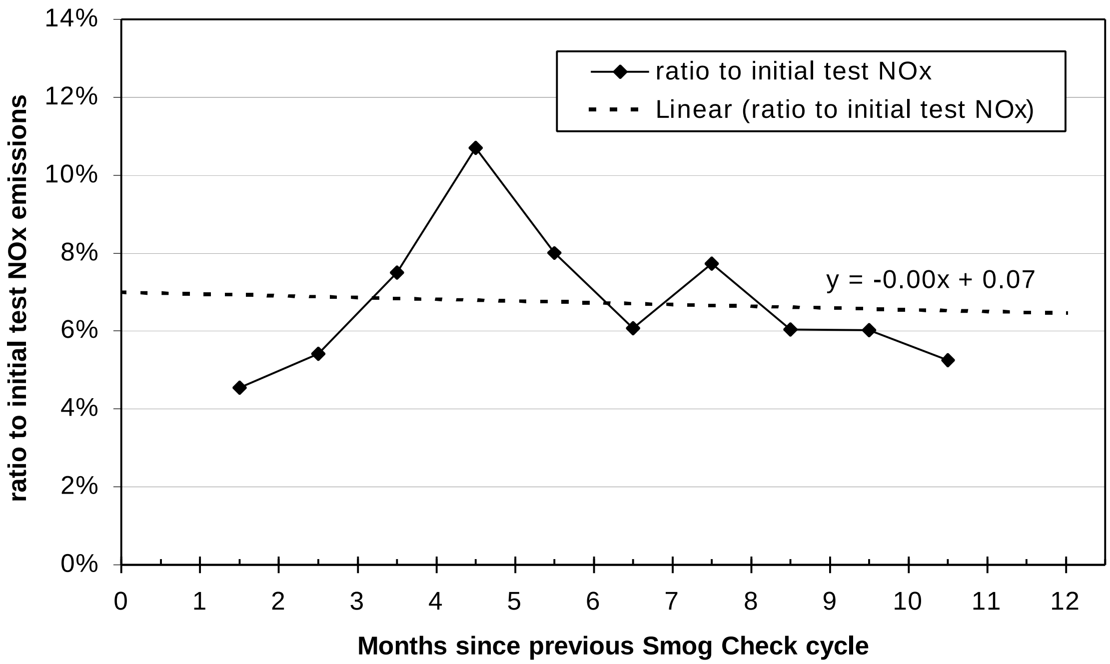


Figure D.4. Ratio of NOx emissions from multi-cycle fleet initial pass vehicles to their previous test emissions, by time since initial Smog Check cycle.



emissions 24% higher if the initial pass fleet were tested immediately after their initial passing test. (For NOx we plot the first 12 months of data, excluding the vehicles tested up to one month after their initial test; this results in our estimate that the average NOx of the initial pass fleet would be 7% higher on an immediate re-test.)

To the extent that fast-pass only minimally affects fleet-average emissions, and that the initial Smog Check for all vehicles in the combined fleet and the second Smog Check for initially passing vehicles were conducted in a completely unbiased fashion, the results of this analysis should be valid. We acknowledge however that we know little about the truth of these assumptions, and thus characterize this analysis only as an estimate of the potential effect of regression to the mean on calculated Smog Check benefits.

The estimated regression to the mean effects were applied in the benefits calculations as follows. Initial (failing) test emissions of fail-pass and no-final-pass vehicles, for model years 1974-1992 only, were adjusted according to the estimated regression to the mean effect on final-pass vehicles. All benefits calculations for repair and replacement were then repeated using the adjusted initial emissions values. Regression to the mean adjustments were made only for 1974-1992 vehicles because only these model years were included in the multi-cycle data used to estimate this effect. A single factor was used for all model years even though the effect may vary with vehicle age. There were insufficient data in the multi-cycle fleet to evaluate this by model year. Our best estimate of overall program benefits, including regression to the mean effects, for post-inspection and repair and vehicle replacement, are presented in Table D.13 (the benefit from pre-inspection maintenance and repairs should not be affected by regression to the mean).

Incorporating the regression to the mean effects reduces our best estimate of exhaust emissions program benefits to 75 tons per day of HC, 1,347 tons per day of CO, and 56 tons per day of NOx.

Table D.13. Estimated total tons of pollutant emissions prevented by the Enhanced Smog Check program, *including regression to the mean effects* (see text for details).

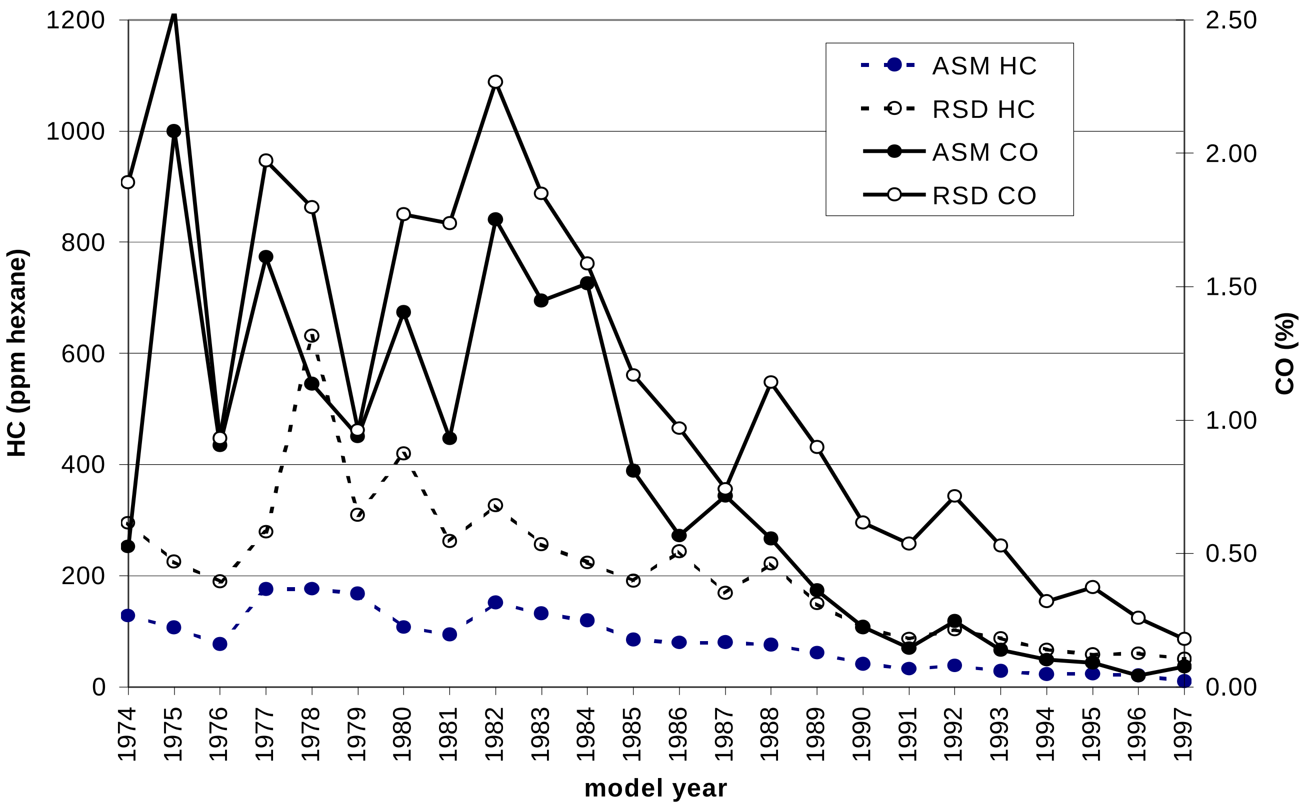
Model	Best Estimate Post-Test Repair			Best Estimate No-Pass Removal		
Year	HC	CO	NOx	HC	CO	NOx
1974	0.61	3.27	-0.21	0.19	1.05	-0.01
1975	0.70	0.80	0.06	0.14	0.96	0.00
1976	0.92	7.14	-0.10	0.24	1.55	0.00
1977	1.47	8.77	-0.06	0.36	2.70	-0.01
1978	1.65	14.21	0.33	0.38	3.76	0.00
1979	2.16	19.85	0.12	0.53	4.71	0.02
1980	1.58	20.38	0.09	0.37	5.46	0.03
1981	1.77	24.70	0.56	0.44	6.33	0.10
1982	2.13	28.28	0.95	0.49	6.76	0.22
1983	2.45	39.50	1.37	0.52	7.76	0.28
1984	3.63	63.52	1.86	0.76	13.16	0.47
1985	3.56	60.79	2.26	0.68	11.48	0.48
1986	3.68	59.02	2.65	0.55	8.48	0.47
1987	3.99	69.09	2.76	0.53	8.86	0.45
1988	3.23	42.35	3.11	0.40	5.06	0.40
1989	2.93	35.73	3.14	0.30	3.39	0.33
1990	2.20	22.36	2.59	0.18	1.64	0.23
1991	1.46	19.39	2.09	0.12	1.09	0.17
1992	1.01	13.30	1.32	0.07	0.58	0.10
1993	1.24	14.35	1.68	0.06	0.59	0.08
1994	0.54	6.77	0.85	0.03	0.32	0.04
1995	0.66	9.63	0.92	0.03	0.34	0.04
1996	0.07	1.24	0.02	0.00	0.05	0.00
1997	0.05	1.76	0.08	0.00	0.06	0.00
1998	0.03	0.60	0.02	0.00	0.02	0.00
1999	0.01	0.14	0.00	0.00	0.01	0.00
Total tons per day	43.7	587.0	28.4	7.4	96.2	3.9

D.9. Relationship between ASM and on-road emissions measured by remote sensing

As discussed throughout the report, the static loaded modes of the ASM test represent artificial conditions that are rarely encountered in real world urban driving. Unfortunately, there is no validated methodology for translating emissions reductions measured on the ASM test to emissions reductions in typical on-road, transient loaded-mode driving. This section compares vehicle emissions as measured under the artificial conditions of the ASM test and as measured by remote sensing.

We present comparisons of ASM and remote sensing emissions for two cases. The first uses remote sensing measurements that were collected at the random roadside test stations, as vehicles were pulling into the station. CO and HC concentrations were measured for nearly 2,000 vehicles that were subsequently tested using the ASM procedure. Average remote sensing and ASM emissions results by model year are presented for these vehicles in Figure D.5 below. The second case compares the average remote sensing emissions measured at the three Los Angeles area sites described in Section 4.2.2 to the average ASM 2525 emissions of all Los Angeles area vehicles during their initial Smog Check tests (from VID data). Average remote sensing and ASM emissions factors are compared by model year in Figure D.6 below. Note that in both cases HC and CO emissions measured under the ASM test are substantially lower than as measured with remote sensing. BAR points out that when vehicles that pass the roadside ASM are excluded from the comparison presented in Figure D.5, the difference between ASM and remote sensing emissions disappears. We are continuing to investigate the possible causes of this discrepancy, in order to better understand any potential biases in the ASM measurements.

Figure D.5. Average emissions of approximately 1,900 vehicles as measured by remote sensing and ASM 2525 during random roadside testing.



Joel Schwartz

Figure D.6. Average emissions of 23,400 vehicles measured by remote sensing at three Los Angeles area sites and average ASM 2525 measured during the initial Smog Check test of all Los Angeles area vehicles in 18 months of Vehicle Information Database data. The vehicles measured by remote sensing were all tested in the Enhanced Smog Check program either before or after they were measured on-road.